THE EFFECTS OF A GRADUAL SHIFT ROTATION AND A SPLIT SHIFT NAP INTERVENTION ON COGNITIVE, PHYSIOLOGICAL AND SUBJECTIVE RESPONSES UNDER SIMULATED NIGHT SHIFT SETTINGS

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ABSTRACT

Introduction: Shift work, particularly work that occurs at night has been associated with numerous challenges to occupational safety and productivity. This stems from the associated extended wakefulness, circadian disruptions and sleep loss from the inversion of the sleep wake cycle, which predisposes shift workers to reduced alertness, increased fatigue and decrements in performance capacity. These effects may be exacerbated over consecutive night shifts as a result of reductions in sleep length associated with attempting to sleep against the alerting signals of the circadian rhythm during the day. Although a variety of shift work countermeasures exist, new and innovative fatigue management strategies are needed to mitigate the effects of night work. This study proposed two night shift interventions; the *Rolling rotation* and a split shift nap combination.

Aims: The aim of this study was to explore the effects of these interventions to a conventional *Fixed night* shift arrangement. Selected performance, physiological and subjective measures were applied to track any effects during a five-day shift work study.

Methods: The study was laboratory-based and performance was quantified through the application of computer-based perceptual, cognitive and motor tests. Student participants (24 females and 21 males) partook in the study, which adopted a non-repeated measures design and spanned five consecutive days. During this time, participants were required to perform a simple beading task over five 8-hour shifts. Participants were split according to sex and chronotype between four independent conditions;

1. *Fixed night* condition required participants to complete one afternoon shift (14h00 – 22h00) and four consecutive night shifts (22h00 - 06h00)
2. *Rolling rotation* condition gradually “rolled” participants into the night shift by delaying the start and end of an afternoon shift by two hours each day (16h00 – 00h00, 18h00 – 02h00, 20h00 – 04h00, 22h00 – 06h00) until the times matched that of the *Fixed night* condition.

3. The split shift nap system was made up of two independent groups, both of which completed one afternoon (14h00 to 22h00) and four night shifts. The *Nap early* condition worked from 20h00 to 08h00, napping between 00h00 and 04h00, while the *Nap late* condition worked from 00h00 to 12h00 and napped between 04h00 and 08h00 during the night shifts. Napping, the opportunity for which was 200 minutes occurred in the laboratory, but post shift recovery sleep, for all conditions, happened outside the laboratory.

During each shift, six test batteries were completed, in which the following measures were taken:

1. Performance: beading output, eye accommodation time, choice reaction time, visual vigilance, simple reaction time, processing speed and object recognition, working memory, motor response time and tracking performance.
2. Physiological: heart rate, heart rate variability (r-MSSD, normalised Low frequency power: LFnu).
3. Self-reported measures: subjective sleepiness and reported sleep length and quality while outside the laboratory.

Results: Analyses revealed that:

1. Measures of beading performance, simple reaction time, vigilance and object recognition, working memory, motor response time and control, all physiological measures, except LFnu and subjective sleepiness demonstrated the effects of time of day / fatigue, irrespective of condition.
2. There was no evidence of cumulative fatigue over the four night shifts in the performance and subjective measures and most of the physiological indicators. Beading output decreased significantly over the course of the night shifts, while reported post shift sleep length was significantly reduced with the start of the night shifts, irrespective of condition.
3. The majority of the physiological and performance measures did not differ significantly between conditions. However, there were some effects: the *Rolling rotation* condition produced the highest beading output compared to

the *Nap late* condition; working memory was significantly lower in the *Nap late* condition compared to the other conditions. Furthermore, the nap opportunity in both the *Nap early* and *Nap late* conditions reduced subjective sleepiness, while napping during the night shift reduced post shift sleep length compared to the *Rolling rotation* and *Fixed night* conditions. There was also evidence of sleep inertia following pre-post nap test comparisons, which mainly affected visual perception tasks in both nap conditions. Sleep inertia possibly also accounted for an apparent dissociation between subjective and performance measures.

Conclusions: Quantifying and interpreting the effects of night shift work in a laboratory setting has limitations. These stem mainly from the limited ecological validity of the performance outcome measures adopted and the characteristics of the sample that is tested. However, in order to fully understand the efficacy of any shift work countermeasure, the laboratory setting offers a safe, controlled environment in which to do so. The conclusions should thus be considered in light of these limitations.

Night shift work negatively affected all elements of human information processing. The combination of reduced physiological arousal, extended wakefulness, increased perceptions of sleepiness and reduced total sleep obtained explained these decrements in performance. While cumulative fatigue has been reported as a challenge associated with night shift work, there was no conclusive evidence of this in the current study. In the case of the *Rolling rotation*, the gradual introduction to the night shift delayed the inevitable reduction in alertness and performance, which limits the viability of this intervention. The inclusion of the nap interventions was associated with reduced perceptions of sleepiness, which did not translate into improved performance, relative to the *Rolling rotation* and *Fixed night* conditions. Apart from considerations of how to manage sleep inertia post nap, the split shift nap intervention can provide an alternative to conventional night shift work arrangements.

This dissertation is dedicated to my father, ***Vincent John Davy****. I miss you dad, every day.*

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CHAPTER 1: INTRODUCTION

The inclusion of night shift work (work that occurs roughly between 22h00 and 06h00: Åkerstedt, 1998) and its effects on human alertness, performance and health in different occupational contexts, has been and remains a challenge to occupational safety and productivity (Knauth and Rutenfranz, 1976; Knauth *et al*., 1980b; Costa, 1996; Åkerstedt, 1998; Folkard and Tucker, 2003; Takahashi, 2014). Essentially, conflict arises between the needs of a work place to remain productive and competitive around the clock and the capability of humans to perform proficiently at times of the day at which they are not suited to perform biologically. Although research has developed some strategies to assist shift workers to perform at night and generally during shift work (reviewed in Åkerstedt and Lundtsrom, 1998; Knauth and Hornberger, 2003; Bonnefond *et al*., 2004; Caldwell *et al*., 2008; Pallesen *et al*, 2010; Lerman *et al*., 2012; Satterfield and Van Dongen, 2013; Williamson and Friswell, 2013; Takahashi, 2014), losses in productivity, accidents and deaths relating to fatigue and sleepiness are still very real occupational and broader societal challenges.

In light of this, there is still a need to better understand the complex interaction of factors that lead to a reduced capacity to perform at night, as well as how the impact of this expected reduction can be minimised through appropriate, context-specific strategies. This thesis focuses on understanding the fatiguing effects of entering into and working consecutive night shifts. Further, it aims to determine if these fatigue effects can be managed through two novel interventions, relative to an established shift work regime. More specifically, it aims to determine whether an alteration in the speed of transition into night work can assist in lessening the fatigue effects of entering the night shift. Furthermore, this study aims to understand whether a prolonged nap intervention, as part of split shift arrangement, affects selected responses.

1.1 BACKGROUND TO THIS STUDY

1.1.1 The challenges associated with shift work

Shift work enables round-the-clock production and the constant provision of essential services. However, such working time arrangements may compromise worker alertness, performance, health and general safety (Åkerstedt, 1990; Folkard and Åkerstedt, 2004; Folkard, Lombardi and Spencer, 2006; Tucker and Folkard, 2012; Rajaratnam *et* al., 2013; Takahashi, 2014). In particular, the problems with night shift work arise from the disruptions to the circadian, sleep and social rhythms caused by working at night, and the resultant fatigue, sleepiness and performance decrements that develop (Czeisler *et al*., 1982; Åkerstedt, 1998; Horowitz *et al*., 2001; Costa and Sartori, 2007). A career that involves these constant disruptions has been associated with negative health outcomes including cancer, sleep and metabolic disorder development, cardiovascular and gastrointestinal disease (reviewed in Knutsson, 2003; Takahashi, 2014). There is also some evidence of shift work being associated with the development of a host of psychological problems, as well as deteriorations in cognitive functions over time (Marquie *et al*., 2014). Work stress may further be accentuated by increasing work family conflicts (discussed in Fagan *et al.,* 2012). Additionally, an increased injury risk and reductions in productivity have been identified as challenges that need to be managed in the context of atypical work schedules (discussed in Folkard and Tucker, 2003; Folkard and Åkerstedt, 2004). More broadly, these effects also impact the general population, albeit indirectly.

In sum, the practise of shift work, although important from an economic perspective, presents numerous and in some cases, long lasting, negative effects on the workers involved and society at large. While these long term effects require more research in order to fully understand the potential causal mechanisms, they are beyond the scope of this thesis. Of more relevance in this context are the short term effects of working shifts, particularly those scheduled during the night.

1.1.1.1 Immediate effects of night shift work

The first night shift presents a major challenge to shift worker alertness, performance and, as a practical consequence, occupational productivity and public safety (Purnell *et al*., 2002; Lamond *et al*., 2003; Lamond *et al*., 2004; Santhi *et al*., 2007; Horne, 2012). This arises from the fact that workers may start the night shift having been awake for up to 16 hours or longer (Folkard, 1992; Sack *et al.,* 2007). Such extended periods of wakefulness alone can result in increased fatigue and sleepiness (Santhi *et al*., 2007). These effects interact with and may be amplified by the natural, circadian modulated reductions in physiological arousal. Together, these processes contribute to reductions in alertness and the general capacity to perform (reviewed in Van Dongen and Dinges, 2003; Rogers *et al*., 2003; Folkard and Tucker, 2003). In turn, working in this state can further contribute to increased accident likelihood, compromised safety and reduced productivity of the employees working such schedules (Moore Ede and Richardson, 1985; Smith *et al*., 1994; Rajaratnam and Arendt, 2001; Folkard and Tucker, 2003; Wagstaff and Lie., 2011). These effects may also have implications for the safety of and service provision to the general public.

Over consecutive night shifts, these negative effects can be exacerbated by the cumulative sleep loss (Drake *et al*., 2001; Van Dongen *et al*., 2003a; Belenky *et al*., 2003) which results from reduced quality and quantity of recovery sleep (one to four hours less than normal) (Åkerstedt *et al*., 1991; Rosekind *et al*., 1994a; Davy and Göbel, 2013). This is attributable to shift workers attempting to sleep against the biological, domestic and societal pressures to be awake (Czeisler *et al*., 1990). Cumulative sleep loss has previously been associated with dose-dependent decrements in cognitive function and reduced subjective awareness of these impairments (Van Dongen *et al*., 2003a; Belenky *et al,* 2003). In light of these observations, the management of these challenges is critical to ensuring the safety and health of the working population involved in atypically timed work.

1.1.2 Shift / night work countermeasures

The literature surrounding shift work countermeasure research is extensive (reviewed in Åkerstedt and Lundstrom, 1998; Bonnefond *et al*., 2004; Caldwell *et al*., 2008; Pallesen *et al*., 2010; Lerman *et al*., 2012; Satterfield and Van Dongen., 2013; Takahashi, 2014). Despite this, there are no universally applicable recommendations as how best to manage the effects of night work. This is due mainly to the variety of the working time arrangements in different contexts, the countermeasures that have been applied and studied and the inconsistent and heterogeneous findings that have resulted.

In brief, effectively-timed rest breaks (eg: Tucker, 2003; Tucker *et al*., 2003; Lombard, 2010), the ingestion of caffeine (eg: Reyner and Horne, 1997; Schweitzer *et al*., 2006) and other stimulants such as modafinil (eg: Hart *et al*., 2006; Czeisler *et al*., 2005) have been effective in managing sleepiness under night shift work conditions. The inclusion of physical activity (eg: Buxton *et al*., 2003; Lombard, 2010; Sato *et al*., 2010) if the task does not already involve physical work can improve alertness in these contexts as well.

The use of bright light can assist with awkward hours of wakefulness associated with shift work, given the human circadian rhythm's sensitivity to light (Czeisler *et al*., 1990; Khlasa *et al*., 2003). Extensive research has revealed that phase delays or advances can be achieved which facilitates some degree of circadian adaptation to working at night and sleeping effectively during the day (eg: Czeisler *et al*., 1989; Bjorvatn *et al*., 1999; Horowitz *et al*., 2001; Smith *et al*., 2008; Smith *et al*., 2009). Additionally, the use of exogenous melatonin after night work (eg: Sharkey *et al*., 2002), manipulating light exposure during the day time (Dumont *et al*., 2009) and combinations of these and other strategies (such as the use of dark glasses in the morning; Crowley *et al*., 2003; Smith *et al*., 2008) can aid in promoting partial circadian adaption to work at night. Other strategies revolve around how shift work is organised and the implementation of strategic napping.

1.1.2.1 Organisational strategies for shift work design

With reference to shift system design, there is consensus that there is no ideal shift system (Knauth, 1993; Kundi, 2003; Ferguson and Dawson, 2012). However, general ergonomics shift system design recommendations can reduce the negative effects of night work, despite the fact that studying these in isolation is challenging. Limiting the number of consecutive night shifts may decrease the abovementioned cumulative sleep loss and its associated effects on alertness and the disruptions to the circadian rhythm (Knauth, 1993; Kundi, 2003; Knauth and Hornberger, 2003; Folkard and Åkerstedt, 2004; Sallinen and Kecklund, 2010). This may be achieved through rapid shift rotation (every 1 to 3 days) as opposed to slower rotation (Hakola and Härmä, 2001; Härmä *et al*., 2006), although there is some support for slow rotation or permanent night shift work (Wilkinson, 1992; Pilcher *et al.,* 2000). An additional recommendation is forward or clockwise rotation, which, from a circadian perspective is more favourable than a backward or anti-clockwise shift rotation (Czeisler *et al*., 1982; Barton and Folkard, 1993; van Amelsvoort *et al*., 2004). Workers should also have enough time between shifts (at least 11 hours) to commute and still have an adequate time frame in which to obtain sufficient sleep. Furthermore, quick returns should also be limited as much as possible to ensure adequate recovery between shift rotations (Hakola *et al*., 2010; Vedaa *et al*., 2015). With respect to shift start times, night shifts should not start or finish too late, as this may interfere with post shift recovery sleep during the conventional day (Kecklund and Åkerstedt, 1995). Furthermore, extended shifts (over 8 hours) should only be considered if the workload and exposure to any inherent work risks is appropriate (Knauth, 1993; Knauth, 2007). More recently, there has been growing focus on increasing flexibility in work through self-rostering. This is a complex issue and beyond the scope of this thesis.

1.1.2.2 Napping strategies during night shift work

In addition to organisational strategies, the practise of napping has and still is considered as an effective countermeasure during night shift work. However, despite extensive research surrounding the effectiveness of nap inclusion during shift and night work, there is still no consensus as to what constitutes the ideal length or timing of naps during night shifts (Dinges *et al*., 1987; Garbarino *et al*., 2004; Hofer-Tinguely *et al*., 2005; Gillberg, 1984; Rogers *et al*., 1989; Rosekind *et al*., 1994(b); Sallinen *et al*., 1998; Takeyama *et al*., 2002; Smith-Coggins *et al*., 2006; Kubo *et al*., 2007; Lovato *et al*., 2009; Signal *et al*., 2009; Davy and Göbel, 2013; Shea *et al*., 2014). This stems mainly from different methodological approaches that have been adopted in the study of napping strategies (Ruggiero and Redekker, 2014). These methodological differences refer mainly to the study of naps of varying lengths and timing, in real world or laboratory contexts and under partial or extended sleep deprivation.

With specific reference to nap length, shorter naps (10 to 40 minutes) are generally recommended over extended naps (>1 to 2 hours) during actual night shifts (Tietzel and Lack, 2002; Brooks and Lack. 2006). Shorter naps are typically compatible with normal break schedules, which facilitates the logistical challenges, while also limiting the risk of sleep inertia (a period of hypovigilance that may occur upon awakening), which may interfere with post nap performance. However, the timing of the nap, the extent of prior wakefulness and sleep stage that an individual awakens in need to be considered in addition to nap length and the risk of sleep inertia (Tassi and Muzet, 2000; Scheer *et al*., 2008). On the other hand, the benefits associated with sleep are dose dependent; the longer a sleep period, the longer lasting the positive effects will be post nap (Bonnet, 1991; Lack and Lovato, 2010). Therefore, it would seem logical that greater benefits would accrue from longer nap opportunities. However, extended naps are typically followed by sleep inertia or post sleep grogginess, particularly if waking occurs during the circadian low. The presence of sleep inertia may therefore mask the nap benefits for anything from minutes to hours post nap (Jewett *et* al., 1999; Tassi and Muzet, 2000; Kubo *et al*., 2010; Lovato and Lack., 2010), which warrants careful management of these effects.

From a practical perspective, the inclusion of extended naps also present logistical challenges around covering work time lost while workers nap (Bonnefond *et al*., 2004). This has been overcome by the introduction of protected sleep periods or split duty periods, during which extended nap opportunities are afforded while work time is covered by additional personnel (eg: Arora *et al*., 2006; Volpp *et al*., 2012; Shea *et al*., 2014; reviewed in Short *et al.,* 2015). Protected sleep periods / split duty periods provide an opportunity to obtain decent sleep at the correct time of day, which supplements the post shift day sleep that is normally curtailed. Such arrangements could limit the negative effects of the first and subsequent night shifts, by supporting the chronobiological and homeostatic need for sleep, while providing individuals with a decent [length] napping opportunity. These arrangements have previously been researched during extended night shifts (Arora *et al*., 2006; Shea *et al*., 2014), in marine and rail watch systems (reviewed in Short *et al*., 2015) and sleep deprivation studies (Dinges *et al*., 1988; Bonnet, 1991), but there is limited research on their efficacy during conventional eight hour shifts, in conjunction with a split shift arrangement.

Irrespective of how a shift system is designed or what countermeasures are implemented, workers will always have to cope with the circadian and sleep-related challenges associated with the first night shift. Moreover, the cumulative sleep deficits that occur over consecutive night shifts may accentuate the effects of the initial night shift, leading to performance decrements towards the end of a series of nights. Previous research in the fields of chronobiology, sleep and general occupational health has been instrumental in reducing the difficulties faced by shift workers. The use of stimulants can improve alertness during the first and subsequent night shifts, but their long term use can result in other health issues. A similar dilemma is faced with the use of sleep medication. The inclusion of rest breaks (with or without physical activity) is essential, but their effects can be transient and cannot be relied upon exclusively to limit sleepiness and fatigue during night shifts. The effective use of bright light, melatonin and other chronobiotic countermeasures can facilitate adaptation to night work, but these methods can be expensive and at times impractical, requiring the support of experts to limit any undesirable effects. Rapidly, forward rotating shifts may limit the cumulative sleep loss and circadian disruptions associated with permanent of slowly rotating schedules, but having to transition into (and out of) night shift work is still unavoidable. Naps taken during the night shift can reduce the homeostatic drive for sleep, by limiting periods of extended wakefulness, which may result in improvements in alertness and performance. Furthermore, extended naps (+ two hours) can provide sustained benefits to performance and alertness when compared to shorter ones, but sleep inertia post nap and the logistics of their inclusion in conventional eight hour shifts has not been systematically investigated.

1.2 STATEMENT OF THE PROBLEM

The transition into the night shift is difficult for shift workers, as they are required to rapidly alter their normal sleep-wake cycle by eight, ten and sometimes 12 hours. Although many different countermeasures have been adopted in an attempt to ease this transition, no studies have explored the effects of a gradual transition into the first night shift. In light of this, the current thesis aims to examine the impact of a *Rolling rotation* intervention, which involved a gradual rotation into the night over four, consecutive days, rather than a rapid one.

A further challenge to working at night is the accumulation of sleep loss that results from attempts to sleep during the day following night work. This raises the question of whether including an opportunity for an extended nap during the night would lessen the detrimental effects being awake at night and accumulated sleep loss. As such, this study explored the effects of splitting a normal eight-hour night shift with an extended nap opportunity.

Despite the logistical challenges associated with both interventions, it would be important to understand their effects, albeit in a simulated context. This is critical, in light of the fact that nearly 100 million people work some form of atypical work shifts each day.

1.3 RESEARCH HYPOTHESES

It was hypothesised that the rapid change (in the sleep wake cycle) to night work would elicit changes in performance, subjective complaints and general physiological arousal. It was further hypothesized that the variations in the abovementioned responses would be intensified over each night shift and over the course of consecutive night shifts. In addition, it was expected that the inclusion of a gradual rotation into the night shift and the inclusion of an extended nap opportunity would result in differential effects in the abovementioned indicators generally, during each shift and over the course of the entire data collection period, in relation to the standard night shift regime[1].

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[1] The corresponding statistical hypotheses are outlined following the explanation of the experimental design in Chapter 3.

CHAPTER 2: REVIEW OF RELATED LITERATURE

2.1 SHIFT WORK

Shift work refers to work that tends to occur outside of the daytime third of the 24-hour day, usually involving more than one team of workers (Åkerstedt, 1998; Costa, 2003; Åkerstedt and Wright, 2009). Such work hours, which vary significantly between different work contexts, include rotating, permanent or irregular shifts that differ with respect to length, direction and speed of rotation and the organisation of break days (Åkerstedt, 1998; Costa, 2003; Sack *et al*., 2007; Sallinen and Kecklund, 2010). The inclusion of night work, defined as work that occurs between 22h00 and 06h00 (Åkerstedt, 1998), or work that falls outside of the normal working hours (07h00 to 18h00) (Monk and Folkard, 1992) or hours of work between 00h00 and 05h00 (EU Working Time Directive, 2003), is an integral part of shift work. These atypical work hours are commonplace and facilitate round-the-clock production and the constant provision of services for a variety of social, technical and economic factors (Angersbach *et al*., 1980; Kogi and Thurman, 1993; Costa, 2010; Ferguson *et al*., 2012a).

It is estimated that approximately 15% to 20% of the world's working population are involved in some form of shift work (Wright *et al*., 2013). In Australia, Rajaratnam *et al*. (2013) posit that 1.5 million people (or 16% of the population) are shift workers. The Japanese Ministry of Health, Labour and Welfare (2007; cited in Takahashi, 2014) estimates that 27.3% of workers in Japan are shift workers, while in the United States and European countries, the figures are closer to 28.3% (Alterman *et al*., 2013) and 17 % (Eurofound, 2010) respectively. With these figures in mind, it is not unexpected that sleepiness-related road and workplace accidents cost the United States between $71 and $93 billion US in 2009, to which shift work was a major contributing factor (Culpepper, 2010).

Research surrounding the effects of shift work and particularly that involving working at night have emphasised the possible negative risks to worker health, safety and general wellbeing. Broadly, shift work has been associated with an increased risk of metabolic disorders (Karlsson *et al*., 2003; Suwazono *et al*., 2009), gastrointestinal problems (Knutsson and Bøggild, 2010), negative cardiovascular developments (ischemic heart disease and coronary heart disease) (Costa, 1997; Bøggild and Knuttson, 1999; reviewed in Puttenon, Härmä and Hublin, 2010), psychological instability (discussed in Spurgeon and Cooper, 2000), reproductive issues (Mahoney, 2010), sleep disorder development (Sack *et al.,* 2007), increased strain on social and family relations (Fagan *et al.,* 2012) and cancer (Schernhammer *et al*., 2001, Erren *et al*., 2010). These health issues may also originate or be exacerbated by pre-existing genetic conditions or methods adopted to cope with the effects of shift work, such as smoking, alcohol use and a reliance of caffeine and other stimulants or prescription sleep medication (Kivimäki *et al*., 2001).

Additionally, night shift work is associated with an increased risk of occupational injuries (Smith *et al*., 1994; Frank, 2000; Wong *et al*., 2011) and accidents (Folkard and Åkerstedt, 2004; Folkard *et al*., 2005) the most notable examples of which included disasters such as those at Three Mile Island, Chernobyl and the Exxon Valdez oil spill (Mitler *et al*., 1988), accidents which have a profoundly negative impact on broader society. All of these were attributed to fatigue and sleepiness, the origins of which stem from, amongst other factors, disruptions to the natural circadian rhythm and sleep wake cycle caused by working at night and attempting to sleep during the day (Åkerstedt, 1998; Tucker and Folkard, 2012).

2.2 SLEEP WAKE REGULATION IN HUMANS

Sleep is recognised as being essential for general recovery, energy conservation, the consolidation of memory and the processes associated with learning (Banks and Dinges *et al*., 2007; Mignot, 2008). Under entrained conditions, humans typically sleep during the night and are awake during the day. This sleep-wake cycle is governed principally by two processes, elegantly explained by the “two process model” proposed by Borbély (1982). The model postulates that sleep (and wakefulness) is controlled by the interaction between the natural innate circadian rhythm (Process C) and the sleep homeostatic process (Process S; Figure 1). Originally, the model was conceived to describe how sleep is regulated (which is beyond the scope of this thesis), but experimental evidence has extended its application to explain the effects of the two processes on cognitive performance and subjective alertness (eg: Dijk *et* al., 1992; Dinges *et al*., 1997; Van Dongen and Dinges, 2003). Initially, these two processes are discussed separately and integrated thereafter.

2.2.1 The circadian rhythm

Animals and humans demonstrate relatively consistent rhythms in a number of physiological and behavioural processes that are influenced by changes in external environment, but controlled by an internal body clock (Aschoff, 1965; Minors and Waterhouse, 1986). This clock, which has been identified as the suprachiasmatic nucleus (SCN) located in proximity to the hypothalamus, is the mechanism through which the internal physiological processes of the body synchronise to the external changes in the environment (Stephan and Zucker, 1979; Datta and Mclean, 2007).

This process of synchronisation, referred to as "entrainment" occurs principally through the receipt of light from the surrounding environment, which is the strongest *zeitgeber* or time giver *(*Rusak and Zucker, 1979; Czeisler *et al.,* 1999; Roenneberg and Foster, 1997). Light is received by the photosensitive ganglion cells in the eye, which aid in transmitting this information to the SCN. It is the relatively consistent cycle of light and dark (day and night) that enables the stable phase relationship between internal physiological clock mechanisms and external changes in the environment to be established (Rusak and Zucker, 1979; Boivin and James, 2002; Scheer *et al*., 2008). Other, weaker time givers include food, temperature change, social interaction, sleep, melatonin and physical activity (discussed in Mistlberger and Skene, 2005). Key physiological processes follow and can therefore be used to track this rhythm; these include cyclical variations in body temperature (Aschoff, 1983) and hormones such as cortisol (Hennig *et al*., 1998) and melatonin (discussed in Cajochen *et al*., 2003).

The rhythm itself (whether entrained or not) is characterised by a peak (or *acrophase*) which manifests as a period of heightened physiological alertness, which coincides with increased core body temperature. During this phase, an individual will have difficulties in falling asleep, a period referred to by Lavie (1986) as the "forbidden zone for sleep". Conversely, the trough (or *nadir*), which occurs during the natural night, roughly between 04h00 and 06h00, is associated with the "slowing" of physiological functions, reduced alertness, and an increased propensity for sleep (Czeisler *et al.*, 1980; Van Dongen and Dinges, 2005). A secondary "dip" in physiological alertness (accompanied by increased sleepiness) occurs during the early afternoon (discussed in Monk, 2005a), during which the sleepiness signals are present, but at much lower levels than that during the nadir.

2.2.2 The sleep homeostatic process

In addition to the natural, oscillating CR, Borbély (1982) described a second, synchronous but opposing process referred to as the sleep homeostatic process (Process S). From the point of awakening, sleep pressure (the need for sleep) begins to increase and does so in a linear fashion the longer one is awake (Daan *et al.*, 1984; Borbély and Achermann, 1999). The dissipation of this sleep propensity can only occur during restful sleep. More specifically, an accumulated sleep need is positively correlated with an increase in slow wave sleep, which is the most restorative phase of sleep (Banks and Dinges, 2007).

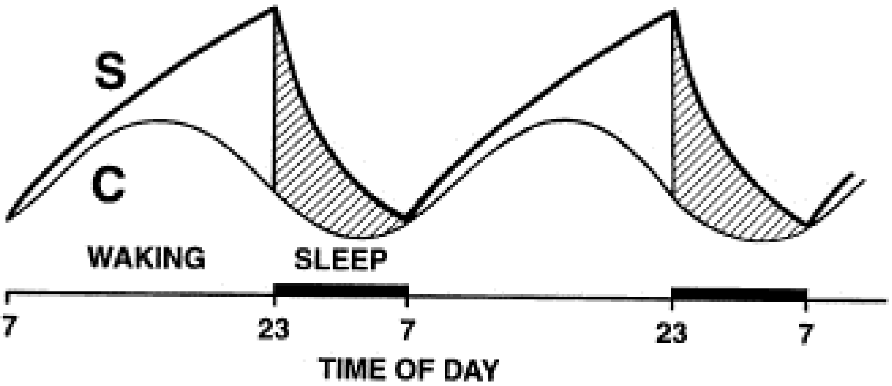

Figure 1: Two process of model of sleep-wake regulation, adapted from Borbély (1982).

2.2.3 The interaction between circadian and homeostatic systems

The interaction between the oscillating circadian pacemaker and the sleep homeostatic process is illustrated in Figure 1. The two processes interact during the habitual night to facilitate and maintain sleep (and recovery): Process C is largely independent of the duration of prior wakefulness and the associated sleepiness. As such, Process C maintains wakefulness and any associated performance requirements during the subjective day, in spite of increasing sleep pressure (Dijk *et* al., 1992; Dijk and Czeilser, 1995; Dijk and von Schantz, 2005). However, at the point where the circadian rhythm favours sleep (usually during the habitual night) and the sleep pressure is high, sleep is difficult to avoid. This also coincides with the release of melatonin from the pineal gland and a concomitant reduction in body temperature following heat loss through increased blood flow to the periphery (Dijk and Cajochen, 1997; Kräuchi *et al*., 2000).

Sleep is initiated on this declining temperature curve (Kräuchi, 2007) and the intensity of Process S is reduced over the course of the sleep period. At the same time, the circadian-related propensity for sleep increases towards the nadir to ensure that sleep is maintained (Dijk and Czeilser, 1995). Waking occurs at the point where sleep pressure has abated and body temperature begins to rise, usually coinciding with daylight hours (Kräuchi, 2007). In essence, the two processes work in opposition to one another to ensure a consolidated period of sleep at night and wakefulness during the day. Thus, the two processes likely contribute to sleep-wake propensity equally (Dijk and Czeilser, 1995). It is this relationship that is upset by the demands of shift and night work.

2.3 UNDERSTANDING THE EFFECTS OF NIGHT WORK

While a variety of environmental, social and behavioural factors can influence sleep, there is consensus that sleep and the regulation thereof is negatively affected by work at night or during the early morning (Knauth *et* al., 1980a; Gold *et al*., 1992; Axelsson *et al*., 2004; reviewed in Åkerstedt, 1998; Åkerstedt, 2007). This interference originates from the temporary desynchronisation between the signals from the environment (namely the light and dark cycle) and natural endogenous circadian rhythm (Minors *et al.,* 1986; Costa and Sartori, 2007). These systems are entrained such that humans are meant to be awake during the day and sleep at night (Åkerstedt and Wright, 2009). The inversion of these rhythms, which has to occur when working night shifts causes shift workers to experience reductions in sleep quality and length, which can in turn lead to cumulative sleep deficits.

Cumulative sleep loss results in increased sleepiness, which negatively affects alertness and consequently performance which can be of concern during consecutive night shifts (eg: Belenky *et al*., 2003; Van Dongen *et al*., 2003a; Cote *et al*., 2008). This is exacerbated by the constant need for readjustment in those workers who are involved in rotating shift work (Folkard, 2008; Costa, 2010). Superimposed onto these effects are the demands of the task (for example, its duration, nature, intensity and degree of control), the predisposition of the worker (such as age, sex, chronotype, motivation, disease and personality) and other socioeconomic factors (reviewed in Di Milia *et al*., 2011 and Saksvik *et al*., 2011). It is the interaction of all these factors that contributes to the development of sleepiness and fatigue. Understanding these two concepts and the complex interaction between multiple contributing factors is critical to determine the most appropriate way to limit their effects and to enhance alertness in occupational settings.

2.3.1 Sleepiness and fatigue

Sleepiness and fatigue are complex phenomena that are typically used interchangeably, as they are difficult to separate (Shen *et al*., 2006). Furthermore, as concepts, they are difficult to define as the experience and explanation of being fatigued or sleepy differs significantly between individuals, between contexts and between disciplines that try to understand their effects. With respect to sleepiness, a generally accepted definition is that it refers to an individual's tendency to need sleep as a result of a high sleep propensity (Shen *et al*., 2006). Johns (1993) conceptualises this further as an experience that results from the interaction of sleep promoting (homeostatic) and wakefulness promoting (circadian) factors. More specifically, sleepiness is purported to result from the dysregulation between these two processes. Fatigue (discussed in more detail in the paragraphs to follow), on the other hand, may also result from this dysregulation as well, but necessarily so (Saper *et al*., 2001; Shen *et al*., 2006). This is the first distinguishing factor between these two concepts.

The second differentiating factor is the way in which they are measured. Sleepiness, in the clinical sense of the term, is assessed objectively through tests such as the *multiple sleep latency test* (Thorpy *et al.*, 1992) or *maintenance of wakefulness test* (Mitler *et al*., 1982) both of which assess sleepiness through changes in sleep latency (the time it takes to fall asleep) in controlled laboratory settings. Additionally, sleepiness can be assessed subjectively through measures such as, inter alia, the Epworth Sleepiness scale (ESS) (Johns, 1991), the Standford Sleepiness scale (SSS) (Hoddes *et al*., 1973) and the Karolinsks Sleepiness scale (KSS) (Åkerstedt and Gillberg, 1990), which provide insights into the presence of sleepiness either as a pathology (ESS) or as a state at a particular point in time (SSS and KSS). In contrast, understanding and measuring fatigue presents more challenges due to the complex interaction of sleep, task, environmental and general dispositional factors (which includes sleepiness) (Shen *et al*., 2006). As such, for pragmatic reasons, the terms fatigue, as opposed to sleepiness, is commonly applied in shift work settings to understand the effects of such working time arrangements on human performance. The concept is thus expanded upon in the following paragraphs.

2.3.2 The concept of fatigue

Researchers across a number of fields concede that the exact definition of what fatigue is remains elusive (Ream and Richardson, 1996; Aaronsen *et* al., 1999; Lal and Craig, 2001; Desmond and Hancock, 2001; Noy *et al*., 2011) as it is not a “single, definite state” (Grandjean, 1979, p175). This is attributable to the fact that the exact causes of this “condition” are still not fully elucidated; that direct measures of the condition still elude researchers and that its development arises from the interaction of several factors (Williamson *et al*., 2011, Di Milia *et al*., 2012; Saxby *et al.,* 2013). The term is typically associated with negative connotations, such increased mood disturbances, reductions in cognitive performance and an increased risk of accidents, injuries and losses in productivity (Mitler *et al.* 1989; Lamond and Dawson, 1999; Williamson and Friswell, 2013). However, fatigue is also a necessary protective mechanism, designed to ensure that restoration and recovery occur, that homeostasis is maintained (Aaronson *et al*., 1999) and that exhaustion does not ensue (Grandjean, 1979).

Broadly, Hitchcock and Matthews (2005) refer to fatigue as a term to describe the many physical and mental responses experienced after extended or taxing work. In this context, physical fatigue is characterised by a reduced force producing capacity following physical exertion (Grandjean, 1979; Lal and Craig, 2001) and diminished movement coordination (Grandjean, 1979). In contrast, mental fatigue can arise through reduced motivation, efficiency and alertness during or following task performance (Grandjean, 1979). This is typically the case in tasks that require attention for extended time periods. Furthermore, fatigue can also either be acute or chronic in nature, which in turn dictates how long it will take to recover from (Aaronsen *et al*., 1999).

Fatigue may also be characterised by reduced efficiency, perceptions of weariness (Lee *et al*., 1991) and an unwillingness to work (Grandjean, 1979). These observations were supported during the early Cambridge cockpit studies during which the classic signs of fatigue (inter alia, inappropriate and untimely responses, tunnel vision and slowed reactions; Drew, 1940, as cited by Miller, 2012) were observed in pilots during extended flights. Brown (1994) extends Grandjean's proposition by emphasising the importance of the subjective perceptions that influence an individuals' willingness to continue with task performance. This supports the assertion by Bartley and Chute (1947: as cited in Ackerman *et al*., 2012) that fatigue is indeed, a very individual-specific experience, while also being an experience that an individual is more often than not aware of (Aaronsen *et al*., 1999).

A further distinction can be drawn between the mechanisms that lead to active and passive fatigue (Desmond and Hancock, 2001) which are principally related to the nature of the task being performed. Active fatigue results from over arousal due to increasing task difficultly or complexity or the need to consistently adjust performance based on changes in the environment or task (Desmond and Hancock, 2001; Saxby *et al*., 2008; Saxby *et al.,* 2013). In contrast, passive fatigue is the product of reduced arousal due to the need to monitor a system, without necessarily having to make adjustments (Desmond and Hancock, 2001). Consequently, passive fatigue is associated with reduced alertness that results from such conditions during which an individual is under-loaded (Desmond and Hancock, 2001; Saxby *et al*., 2008; Saxby *et al*., 2013). This is similar to, but should be distinct from the manifestation of boredom, where constant repetitions of the same task in a monotonous environment, results in reduced alertness and performance (Grandjean, 1979). This effect is encapsulated in the inverted U theory (Yerkes and Dodson, 1908, as cited in Watters *et al*., 1997), which describes how tasks that are unstimulating can result in boredom and consequently compromised performance.

In addition to the characteristics of the task, the inherent interest in it and whether it is self or externally paced can affect the “flow” of the task (Hockey, 2012). Interference in the flow or interest in a task can result in a disengagement from it, which could also negatively affect performance during it (Tremaine *et al*., 2010). This is further exacerbated by the time-on-task effects (Mackworth, 1948; Lim *et al*., 2010) and the frequency of the break opportunities (reviewed in Tucker, 2003).

In the context of shift work and particularly work at night, the effects of the natural circadian-related down regulation in arousal, the interaction with the sleep homeostatic process, the reduced sleep quality and length and the abovementioned factors are likely the most significant contributing factors to fatigue.

2.3.2.1 Circadian and homeostatic factors and fatigue

Biologically Lal and Craig (2001), preceded by Grandjean (1979) refer to fatigue as a transient state that occurs between wakefulness and sleep, while more recently fatigue has been referred to as a “biological drive for recuperative rest” (Williamson *et al*., 2011; 499). These authors highlight the critical interaction between the circadian-modulated variations in alertness (and subsequently, performance) and the sleep homeostatic process. In the context of night shift work, which is characterised by extended wakefulness and the requirement to work at inappropriate times of day, the development of fatigue is highly probable (Dawson and Reid, 1997; Åkerstedt and Wright, 2009; Rajaratnam *et al*., 2013). The result of the mismatch between circadian and homeostatic factors is physiological sleepiness, which in conjunction with other factors outlined above, contribute to fatigue development. This demonstrates the link between the concepts of sleepiness and fatigue. This assertion further supports the statement by Bartley and Chute (1947) that fatigue results from a conflict: in this case, the conflict arises from the incompatibility between the imposed work schedules and innate sleep-wake cycle of a shift worker.

It is well accepted that alertness and cognitive / mental / neurobehaviorual performance, physiological arousal as well as subjective perceptions of alertness or sleepiness (discussed in the ASSESING THE EFFECTS OF NIGHT SHIFT WORK AND FATIGUE below) are influenced by both the endogenous changes in temperature rhythms as dictated by the circadian clock (Folkard, 1975; Rutenfranz and Colquhoun, 1979; Folkard and Monk, 1980; Wright *et al*., 2002; reviewed in Carrier and Monk, 2000; Schmidt *et al*., 2007; Blatter and Cajochen, 2007; Valdez *et al*., 2008; Goel *et al*., 2013) and its interaction with the sleep homeostatic process (Dijk *et al*., 1992; Van Dongen and Dinges, 2005). Early research by Kleitman (1933) presented compelling evidence that linked the oscillation of various simple task performances with body temperature over the day. Although this relationship is not causal (Folkard and Rosen, 1990), such insights provide a basis upon which other factors that affect performance, such as time awake, degree of prior sleep loss, task characteristics and individual factors can be understood.

More recent research using protocols such as the constant routine (during which circadian masking factors are controlled) have shown this circadian rhythmicity in a number of different performance, physiological and subjective outcomes measures (Dijk *et al*., 1992; Johnson *et al*., 1992; Monk *et al*., 1997). However, the constant routine also reveals the simultaneous influence of extended wakefulness and increased sleep propensity, which can at times mask the circadian-related changes (Dijk *et al*., 1992; Johnson *et al*., 1992; Monk *et al*., 1997). In order to isolate the simultaneous impact of these two processes, the Forced desynchronistion protocols were developed.

Forced desynchronisation (FD) protocols, pioneered by Nathaniel Kleitman (1963; cited in Dijk and Czeisler, 1995) aid in understanding the concomitant and individual effects of *Process C and Process* S, on alertness, performance and perceptions more fully. FD protocols impose longer or shorter virtual day lengths on participants in a highly controlled laboratory setting, which allows researchers to isolate the impact of circadian and homeostatic factors at virtually all hours of the day (Blatter and Cajochen, 2006). More specifically, FD protocols have highlighted how neurobehavioral performance and subjective alertness worsen with increasing time awake, independent of circadian rhythmicity (eg: Dijk *et al*., 1992; Wright *et al.,* 2002; Zhou *et al*., 2010; Zhou *et al.,* 2012). Conversely, independent of the extent of prior wakefulness, neurobehavioral performance tends to mirror the endogenous rhythm (under conditions where the normal *zeitgebers* are not present or are strictly controlled; Wright *et al*., 2002; Zhou *et al*., 2010; Zhou *et al*., 2012). Taken together, the interaction of extended wakefulness (heightened sleep pressure) at a low point in physiological alertness (the circadian nadir) negatively affects cognitive performance and perceived alertness (Dijk *et al*., 1992; Dijk and Czeisler, 1995; Wyatt *et al*., 1999; Horowitz *et al*., 2001; Åkerstedt and Wright, 2009). These observations have assisted in understanding the effects of circumstances in which the relationship between the circadian and homeostatic processes is upset, and how this may contribute to the development of fatigue in shift work settings.

2.3.3 Night shift work

2.3.3.1 The immediate effects of entering the night shift

The proximal challenge associated with working at night, is the first night shift. Several authors (Purnell *et al*., 2002; Santhi *et al*., 2007; Horne, 2012; Pylkkönen *et al.,* 2015) have highlighted the increased risk of reduced alertness and consequent performance decrements that accompany this transition from daytime work hours. The negative effects of the first night shift have also been observed in laboratory settings (Hart *et al.,* 2003; Lamond *et al.*, 2004). This risk stems from the rapid misalignment between the endogenous circadian rhythm and the exogenous sleep-wake cycle imposed by working at night.

Akin to the experience of jet lag, the effects of this rapid eight or 12-hour alteration in typical sleep-wake patterns may be intensified by extended wakefulness prior to starting work; Folkard (1992), Åkerstedt (1998) and Sack *et al*. (2007) report that this period of wakefulness can be anything between 16 and 24 hours. This is of concern as Dawson and Reid (1997), Lamond and Dawson (1999) and Williamson and Feyer, (2000) concluded that 17 hours of wakefulness was comparable to a blood alcohol concentration of 0.05%, which these authors reported to have negative effects of various elements of cognitive performance. However, others (Fietze *et al*., 2009) found that the transition into the night shift did not negatively affect sleep length or efficiency in young nurses.

In addition, workers are typically required to perform during the nadir of the circadian rhythm, a period characterised by high sleep propensity and a reduced capacity to perform. This has repeatedly been demonstrated in laboratory settings using various cognitive tests and subjective measures (Dijk *et* al., 1992; Monk *et* al., 1997; Wright *et al*., 2002; Lamond *et* al., 2004; Ferguson *et al*., 2012b). In their meta-analysis, Folkard and Tucker (2003) showed that productivity across a number of industries was lowest at 03h00. In contrast, these authors reported that risk was highest around midnight, with only a small increase between 03h00 and 04h00.

Together, the incompatibility between the sleep wake cycle of workers and the night shift work hours predisposes individuals to periods of reduced alertness, subjective and objective signs of sleepiness and, at times, sleep onset at work (Åkerstedt, 1988). Moreover, simulated night shift studies (Hart *et al*., 2003; Lamond *et al*., 2004) also reported that over consecutive night shifts, these effects can accumulate and present additional challenges to occupational and public safety.

2.3.3.2 Effects of working consecutive night shifts

Night shift work requires that workers obtain their recovery sleep during normal daylight hours. This misalignment between the sleep-wake cycle imposed by night shift work hours and the endogenous rhythms results in reduced length and quality of sleep: day sleep following a night shift is accompanied by premature awakenings (Åkerstedt *et al*., 1991; Rosekind *et al*., 1996; Åkerstedt, 1998) and a sleep period that can be curtailed by as much as one to four hours (Åkerstedt *et al*., 1991; Holmes *et al*., 2001; Davy and Göbel., 2013). This reduced sleep is the result of attempting to sleep against the alerting signals of the innate circadian rhythm (Czeisler *et al*., 1980). Additional demographic, social, environmental and lifestyle factors may also contribute to reductions in sleep length (Eberhardt *et al*., 1987; Bliwise, 1993; Ferrera and De Gennaro, 2001).

If such a pattern of reduced sleep continues over a number of night shifts sleep loss accumulates in the form of “sleep debt” (Dinges *et* al., 1997; Van Dongen *et al*., 2003b). This refers to the discrepancy between the basal amount of sleep required and actual (reduced) amount of sleep obtained (Van Dongen *et al*., 2003b). The addition of this third compounding factor (to the circadian disruption and extended wakefulness) further reduces an individual’s alertness and capacity to work at night.

In their meta-analyses of relevant literature, Folkard and Tucker (2003), proceeded by Folkard and Åkerstedt (2004) showed that risk increased over consecutive night shifts. These observations are partially supported by the findings of several empirical studies (Dinges *et al*., 1997; Drake *et al*., 2001; Belenky *et al*., 2003; Van Dongen *et al*., 2003a; Cote *et al*., 2008; Haavisto *et al*., 2010) which have found that when sleep is restricted to fewer than six hours per night, deficits in waking cognitive function are evident. Van Dongen *et al*. (2003a) compared the performance and subjective effects of restricted sleep (4, 6 and 8 hours) over 14 days and emphasised that the performance deficits (Psychomotor vigilance speed and lapse frequency) observed were cumulative, dose-dependent and comparable to two nights of complete sleep deprivation. Additionally, these deficits did not change with time of day, which indicates that the typical circadian variations in alertness and performance were not evident. Subjectively participants whose sleep was restricted did not seem to be aware of the degree of impairment reflected in the cognitive measures (Van Dongen *et al*., 2003a). Similar results were obtained by Belenky *et al.* (2003). Although these observations were made during the day time, the findings of these studies stress the risks associated restricted sleep over consecutive days and how this contributes to fatigue. However, the manifestation of fatigue as a result of these abovementioned factors is also mediated by individual factors, which have to be considered in the management of fatigue in any setting.

2.3.3.3 Individual factors and fatigue during shift work

Initially conceived by Andlauer *et al*. (1979), there is evidence to suggest that some individuals tolerate night work better than others (Axelsson *et al*., 2004; reviewed by Kerkhof, 1985, Saskvik *et al*., 2011). The factors that mediate shift work tolerance include *inter alia* age, sex and circadian preference or chronotype. These factors cannot be ignored, as in some cases they may explain certain effects that may not necessarily be due to the conditions of interest only.

2.3.3.3.1 Effect of age

Aging has been associated with altered function of the circadian clock, which is accompanied by disruptions to the sleep wake cycle (Costa and Sartori, 2007). More specifically, increasing age has been reported to be associated with a reduced circadian amplitude, a shift in the circadian rhythm to an earlier phase and a reduced ability to adjust to abrupt phase shifts, such as those associated with shift work (Åkerstedt and Torsvall, 1981; Härmä, 1993; Monk, 2005b). Costa and Di Milia (2008) reported a reduced shift work tolerance in individuals between the ages of 40 and 50 years, but a relatively recent systematic review has shown this not be a consistent finding (Saskvik *et al*., 2011). Reid and Dawson (2001) and Seo *et al*. (2000) stated that being younger was associated with better tolerance to shift work in simulated and real world settings respectively. In contrast, other studies report better tolerance amongst older workers (Winwood *et al*., 2006) or no age differences at all (Härmä *et al*., 2008). The discrepancy, as discussed in the systematic review by Saskvik and colleagues (2011) could be explained by the differences in the outcome measures applied and the shift work schedules in the different studies. Additionally, the "healthy shift worker effect" cannot be ignored. In some cases, older individuals may have chosen to work nights and may experience fewer health issues as a result of developing appropriate coping strategies through experience, when compared to younger or less experienced workers (Knuttson, 2004).

2.3.3.3.2 Effect of sex

As with the effects of age, the sex differences in the degree of shift work tolerance are not entirely clear (Saskvik *et al*., 2011). However, males tend to tolerate shift work better than females. Oginska *et al*. (1993) found that females reported more sleep complaints, were sleepier while at work and experienced poorer health than men in a steel plant. This was in contrast to the observations by Axelsson *et al*. (2004) who found few sex differences in their sample of shift workers.

2.3.3.3.3 Effect of chronotype

Chronotype refers to the individual differences with respect to how that individual's circadian clock alignments to the external "*zeitgebers*" (Juda *et al*., 2013). Simply, it refers to the diurnal preference for the sleep and other activities (Torsvall and

Åkerstedt, 1980). Low morningness scores (being predisposed to being an evening type) have been associated with better tolerance to night work (Furnham and Hughes, 1999; Seo *et al*., 2000). Biologically, this is explained by evening types (ET) possessing a later circadian phase compared to morning types (MT), which tends to influence sleep and waking times. Kerkhof and Van Dongen (1996) determined that there was a two-hour difference in the circadian phase of MT and ET. MT are also less flexible in their sleeping habits in that they prefer to adopt set times to sleep and wake up (Furnham and Hughes, 1999) and in simulated shift work settings, the inclusion of nap during the night was more beneficial to MT performance, but not for evening types (Takeyama *et al*., 2002). There is also evidence to suggest that this relationship is further modified by age as a shift to a greater degree of morningness is associated with increasing age (Carciofo *et al*., 2012).

Other factors that may modify shift work tolerance include genetic predisposition, personality, physical fitness and flexibility in sleeping habits (reviewed in Härmä, 1993; Saskvik *et al*., 2011). Although important to consider, these factors are peripheral to this thesis.

2.4 MANAGING THE EFFECTS OF NIGHT SHIFT WORK

2.4.1 Individual shift work countermeasures

To aid workers with the transition in to and out of night shift work, a multitude of alertness management strategies have been explored (Åkerstedt and Lündstrom, 1998; Bonnefond *et al*., 2004; Caldwell *et al*., 2008; Pallasen *et al*., 2010; Williamson and Friswell, 2013, Neil-Sztramko *et al*., 2014). The use of psycho-stimulating drugs (such as Modafinil) has proven effective in attenuating the cognitive performance deficits associated with working at night by increasing alertness (eg: Wesensten *et al.*, 2002; Walsh *et al*., 2004; Hart *et al*., 2006; Czeisler *et al*., 2005). The use of hypnotics is purported to improve sleep quality following night shift work, which limits cumulative sleep loss over a short term period (Walsh *et al*., 1988; Walsh *et al.,* 1995), but effects of long term use have been discouraged in instances where individuals have to operate motor vehicles (Kripke, 2000). Additionally, the use of caffeine increases the level of arousal and therefore alertness. This has led to improvements in performance in simulated night shift work settings (Walsh *et al*., 1990; Bonnet and Arand., 1994; Reyner and Horne, 1997; Schweitzer *et al*., 2006), while also being reported as one of the most commonly adopted countermeasure in real world settings (Pylkkönen *et al*., 2015). However, Carrier *et al.* (2007) warns that caffeine may interfere with post shift recovery sleep if taken at an inappropriate time of day or night.

The introduction of exercise has in some cases, also facilitated adaptation/phase shifting to night shift work (Eastman *et al*., 1995; Youngstedt *et al.,* 2002; Buxton *et al*., 2003). More commonly, physical activity (included as part of a work break) is used to improve alertness, with some literature highlighting its positive impact on performance and sleepiness (Lombard, 2010; Sato *et al*., 2010). Despite the improvements in physiological arousal that accrue from exercise, Caldwell (2001) warns that the benefits are transient and do not last longer than between 10 and 30 minutes.

Carefully timed exposure to bright light during the night shift has been found to aid in circadian phase changes, which can aid to facilitate adaptation to shift work rather rapidly (Czeisler *et al*., 1990; Bjorvatn *et al*., 1999; Boivin and James, 2002; Bjorvatn and Pallesen, 2009). The relationship between light and its effects on the circadian rhythm is described using the phase response curve (PRC) seen in Figure 2 (Khalsa et al., 2003). The PRC is derived by exposing the circadian rhythm to *zeitgebers* such as light, at different times during the rhythm, and monitoring the effect it has on the phase of the clock (Burgess et al., 2002). In essence, exposure to bright light prior to the nadir results in a circadian phase delay (Czeisler *et al.,* 1990; Dawson and Campbell, 1991; Bjorvatn and Pallesen, 2009), whereas light exposure after the nadir culminates in a phase advance (Khalsa *et al*., 2003). These changes are tracked using core body temperature or other changes in hormonal concentrations, such as melatonin (Benloucif et al., 2005). Any light exposure during the mid-point of the rhythm (during the subjective day) does not elicit any effect and is referred to as the “dead zone” (Czeisler *et* al., 1989; Jewett *et al*., 1997). Shift work researchers and practitioners have explored this relationship and its potential to hasten circadian adjustment to working at night. However, in order to maximise recovery post shift, these individuals need to be isolated from sunlight which may interfere with the recovery process (Smith *et al*., 2009).

In addition to the use of light, the (concomitant) use of melatonin to assist with phase shifting has been explored to aid shift workers (Folkard *et al*., 1993; James *et al*., 1998; Sharkey *et al*., 2001; Burgess *et al*., 2002). Like exposure to bright light, exogenous melatonin consumption at certain times of the day will result in a phase advance or delay (Figure 2): Arendt (2006) reported that the phase response curve for melatonin is opposite to that of late. More specifically, ingesting melatonin prior to the nadir (early evening) will cause a phase advance, while ingestion after the nadir will result in a phase delay (Burgess *et al*., 2002). Although melatonin use has been found to assist with morning sleep following night shift work (Folkard *et al*., 1993), others have found that the associated benefits are minimal due to the inherent circadian disruptions that result from working and rotating in and out of night shifts (James *et al*., 1998; Sharkey *et al*., 2001).

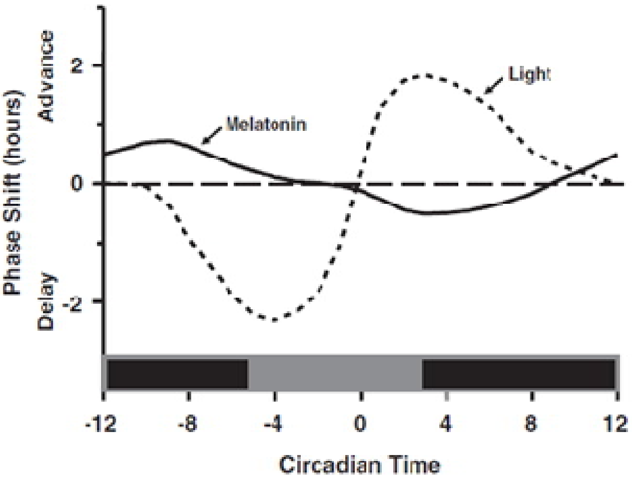

Figure 2: Schematic representation of the phase response curve for light and melatonin. 0 circadian time represents the circadian nadir in this case. (Sourced from Zee and Manthena, 2007 and adapted from Lewy *et al*., 1998 and Khalsa *et al*., 2003).

A combination of bright light and melatonin has proven to be more effective in assisting with night shift work in simulated settings (Dawson *et al*., 1995), but to a lesser extent in real world contexts. This is attributable to the variety of extraneous factors such as task demands and exposure to sunlight that cannot always be controlled (Bjorvatn *et al*., 2007). Additional combinations of bright light, melatonin, use of dark glasses and carefully timed exposure to light and dark periods during the day have been successful and therefore recommended to assist in complete adaption of the CR to night work (outlined in Crowley *et al*., 2003; Smith *et al*., 2008; Smith *et al*., 2009).

2.4.2 Organisational strategies: shift system design

There is consensus that, despite the countless number of shift system arrangements available, there is no optimal shift system design (Wilkinson, 1992; Folkard, 1992; Knauth, 1993; Kundi, 2003; Ferguson and Dawson, 2012). This stems from the fact that any arrangement has broader economic, logistical, safety and social knock-on effects, which make the effects of any design complex. In line with this conundrum Kundi (2003; p302) wrote "there are certain principles (of shift design) that lead to different and often incompatible solutions". This was echoed by Ferguson and Dawson (2012): these authors stressed the importance of considering shift systems as a "complex ecology of interdependent factors" and that their design needs to consider the work pattern, the demographics of the worker and the actual task (Ferguson and Dawson, 2012; p8). Despite this, there are certain elements of a shift system which, if considered carefully from an ergonomics perspective, may result in the "best compromise" shift system, where human safety and economic needs are considered equally (Folkard, 1992; Knauth, 1993).

2.4.3 Ergonomics shift scheduling recommendations

The recommendations surrounding ergonomic shift system has been extensively reviewer (Folkard, 1992; Wilkinson, 1992; Knauth, 1993; Knauth, 1995; Knauth, 1996; Pilcher *et al*., 2000; Kundi, 2003; Knauth and Hornberger, 2003; Driscoll *et al*., 2007; Bambra *et al*., 2008; Sallinen and Kecklund, 2010; Ferguson and Dawson, 2012; Lerman *et al*., 2012). The following checkpoints provide some general guidance in the design of appropriate, protective shift schedules:

1. Reducing the **total number of night shifts**
2. Practising **rapid rotation** of shifts over weekly or permanent night work
3. Favouring **forward rotation** over backward rotation of shifts
4. **Night shifts should not start after 23h00** and morning shifts should not start before 06h00
5. Limiting any quick changeovers or returns

6. Ensuring **adequate break between shifts** (at least 11 hours between shifts).
7. Limiting the working week to between **5 and 7 consecutive days**
8. The inclusion of **extended shifts** should only be considered if:
    - The workload is appropriate
    - The shift system is design in a way so as to limit fatigue
    - That overtime is not added or permitted
    - Exposure to toxic substance is limited
    - If other social, health and contextual challenges are considered (Knauth, 1993)
9. Avoid work on weekends

A further consideration, not discussed here in detail, is the process by which shift systems are implemented through participation of all stakeholders within a working context (see Kogi and di Martino, 1995; Knauth, 2001; Jeppesen 2003).

2.4.4 Considerations pertaining to shift system design research

Research into the efficacy of different shift system designs has been performed in both real world and laboratory contexts. With respect to the former, insights into the effects of interventions on worker perceptions, attitudes, sleep and or health have been monitored over time. These studies are useful in that they provide practical insights into the effects of complex interactions between a number of social, economic and personal factors (Deacon and Arendt, 1996). However, they limit a researcher's ability to collect extensive objective data, for example through performance tests, as these may interfere with the work process. Furthermore, it is difficult to isolate the effects of an intervention due to the complex interaction of organisational, task and personal factors (Ferguson and Dawson, 2012). Such research can also very expensive and time intensive (Deacon and Arendt, 1996).

With respect to laboratory-based research, more control is possible and the ability to isolate (to some extent) certain intervention effects is more plausible (Knauth and Rutenfranz, 1976; Knauth *et al*., 1980b; Reid and Dawson, 2001; Lamond *et al*., 2003; Lamond *et al*., 2004). However, these studies are limited by the lack of ecological validity of some measures and the lack of real world influencing factors.

Irrespective of the limitations of these two contexts, some general recommendations do exist and are expanded upon in the following paragraphs.

2.4.4.1 Rotating or permanent shifts?

In instances where the amount of night shift work cannot be reduced, a general recommendation is that rotating, as opposed to permanent shift work should be practised to limit the total number of consecutive night shifts (Folkard, 1992; Knauth, 1993; Kundi, 1993; Knauth, 1996; Bambra *et al*., 2008). Despite this recommendation, this remains one of the fundamental debates within shift work research (Wilkinson, 1992; Folkard, 1992; Pilcher *et al*., 2000; Folkard, 2008). Fixed night or (very) slowly rotating night work is held to offer certain benefits in terms of aiding worker circadian rhythms to adjust, resulting in improved night time performance and improved post shift sleep (as reviewed by Wilkinson, 1992 and Pilcher *et al*., 2000). However, Folkard (2008) and others have indicated that fewer than one in four permanent night shift workers experience the degree of adaptation from which adjustment benefits are derived (Knauth and Rutenfranz, 1976). This arises from the fact that the implementation of permanent or slowly rotating night work would require workers to remain nocturnally-orientated (even on rest days) so as to remain adjusted, thus forming a “nocturnal sub-society” (Folkard and Rosen, 1990; 95). This can be challenging, particularly when workers have families or wish to engage in social events and revert back to a diurnal orientation on days off work (Folkard, 1992; Tucker and Folkard, 2012).

Rotating shift work, which can occur weekly (rotation after five to seven work days) or more rapidly (rotation every one to three days) is, in most instances, recommended over fixed or semi-permanent night work (Folkard, 1992; Knauth, 1993; Knauth and Hornberger, 2003; Bambra et al., 2008; Sallinen and Kecklund, 2010). Härmä *et al*. (2006) observed that the inclusion of rapid rotation also facilitates more rapid recovery during shift systems that involve night work, while also limiting the accumulation of sleep debt from consecutive, shortened day sleeps (Smith, 1979; Folkard, 1992). In addition to this, rotation is also favoured from a social perspective as workers have more free evenings in a week (Dahlgren, 1981; Folkard, 1992; Knauth, 1993).

2.4.4.2 Considerations around the speed of rotation

With respect to how rapidly shift rotation occurs, some research has concluded that weekly rotations (after five to seven days) are generally associated with most problems as this period of time may facilitate a degree of circadian adaptation and allow for sleep deficits to accumulate (Knauth and Hornberger, 2003; Klein Hesselink *et al*., 2010). In their systematic review Pilcher *et al*., (2000) contradict this assertion, highlighting the benefits of slower rotations on post shift sleep length, in that shift workers sleep is longer. Evidence from laboratory studies (Roach *et al*., 2001; Holmes *et al*., 2001; Lamond *et al*., 2004) and certain real world working conditions (Gibbs *et al*., 2002; Bjorvatn *et al*., 2006; Hansen *et al*., 2010) has demonstrated that a degree of circadian adaptation occurs during one or two week periods of constant night shift work. However, these studies were based in laboratory and insulated work conditions (such as oil rigs) respectively which may favour such circadian adaptation. Contrary to this, Ferguson *et al*. (2012a) found no evidence of adaptation in remote mining conditions, which the authors hypothesised, would be ideal for adaptation. With respect to rapidly rotating shift systems (every one to three days), Folkard and Rosen (1990; 95) holds that shift workers merely “stay up late” but still experience a degree of sleep disruption which needs to be managed through additional appropriate, context-specific strategies.

In their study on emergency controllers, Williamson and Sanderson (1986) found that subjective health, well-being and job satisfaction improved with a rapidly (forward) rotating shift arrangement. This was accompanied by reduced gastrointestinal problems and anxiety. Similarly, Fischer *et al*. (1997) reported better perceived sleep quality following the inclusion of rapid rotation (as compared to weekly rotation) in petrochemical plants in Brazil.

Härmä *et al*. (2006) introduced a rapid forward rotating system and compared it to a previously imposed slower, backward rotating system. The intervention improved sleep length after the night shifts, reduced subjective sleepiness measures during the night and improved performance in the psychomotor vigilance task. Overall, worker perceptions of the intervention were positive in relation to work-life balance issues as well. A similar intervention was implemented and assessed in a steel industrial plant where sleep measures improved, but mainly in older workers (Hakola and Härmä, 2001). Klein Hesselink *et al*. (2011) followed the introduction of a rapidly forward rotating system with an extra day off after night shift work. The intervention resulted in reduced absenteeism in a Dutch steel company. These authors highlighted that the worst observations were made with respect to weekly rotating shift schedules, which again contradicts the assertions made by Pilcher *et al*. (2000). All of the abovementioned studies, although real-world based, emphasise the benefits of reducing the total number of night shifts on various elements of health and wellbeing. This is despite the fact that the data obtained during these studies was mainly questionnaire-based and in most instances, no measures of performance were included. Additionally, the intervention applied was more than just a change in the speed of rotation; the direction of the rotation needs to be considered in parallel to decisions relating to the speed of the rotation.

Summary

Rotating schedules are generally recommended over systems that include permanent or slow rotation. This stems mainly from the inability of shift workers to fully adapt to night shift work on a permanent basis. With respect to the speed of rotation, it is mostly accepted that rapidly rotating shifts are favoured over slower rotations as the rapid change may limit the disruptions to the circadian rhythm. However, isolating the effects of shift rotation speed is difficult if interventions include changes in the direction of the rotation.

2.4.4.3 Backward or forward rotation?

Shifts can rotate in a clockwise (forward), anticlockwise (backward) manner or in a way that combines both (Barton and Folkard, 1993). Generally, the prolongation or delay of the endogenous circadian rhythm (as experienced with forward rotating systems) is recommended over the phase advance that results from backward rotation (Czeisler *et al*., 1982; Knauth, 1993). This is based on the fact that, in the absence of external *zeitgebers* such as sunlight and meal times, the endogenous circadian processes and the sleep wake cycle tend to “free run” with in a period of 25 hours (Achoff and Wever, 1962, as cited in Tucker and Folkard, 2012; van

Amelsvoort *et al*., 2004). It is therefore easier to delay the onset of sleep (through staying up later) than it is to attempt to advance sleep (van Amelsvoort *et al*., 2004).

Further support for the preference of phase delaying rather than advancing systems stems from jet lag studies, during which it has been found that flying in a westward direction (which results in a phase delay and therefore lengthens the “day”) tends to result in faster adjustments than flights in an eastward direction (which results in a phase advance and effectively shortens the “day”; Barton and Folkard, 1993). Lastly, phase delaying systems also limit the incidence of “quick returns” in the context of rapidly rotating shift schedules, discussed below (Barton *et al*., 1994). Quick returns refer to short periods of time that occur between the change from one type of shift to another (afternoon to morning for example). Forward rotation usually allows for a 24-hour break between the shift rotation/change (Barton and Folkard, 1993, van Amelsvoort *et al*., 2004) which provides workers with adequate time for commuting and recovery sleep.

The studies by Härmä *et al.* (2006) and Hakola and Härmä (2001) discussed above emphasised the benefits associated with forward rapid rotation as compared to backward, slow rotations. Czeisler *et al*. (1982) compared the effects of a weekly, backward rotating schedule to a slow, forward rotating one. The authors concluded that a slow, forward rotating shift system was preferable, as it was based on the premise that the human circadian rhythm is longer than 24 hours, and therefore easier to phase delay. Van Amelsvoort *et al*. (2004) also reported that backward rotating schedules were associated with increased need for recovery, poorer health, greater work-family conflict, reduced leisure time and poorer sleep quality over a 32-month period, relative to forward rotation in three-shift workers. In contrast, Åkerstedt (1998) included that anecdotal evidence favoured backward rotating shifts, as it tends to end with night shifts, which results in workers having to spend the first two days of their off duty period recovering. This would however depend on which type of shift (morning, afternoon or night) a particular set of workers began with.

Vangelova (2008) attributed increased levels of fatigue and poorer sleep quality to the effects of backward rotating shifts when compared to forward rotating ones. Similarly, in their comparison between delaying and advancing shift systems among industrial and service workers, Barton and Folkard (1993) reported that the latter were associated with more sleep, social and domestic disruptions, poorer physical and psychological health and increased job dissatisfaction. In 1994, Barton *et al*. monitored the effects of a roster change, specifically those from a weekly, delaying (forward rotating) system to an advancing (backward rotating) system, on worker wellbeing and health. After 8 months, the advancing system was associated with increased dissatisfaction with the system and lower enjoyment of work, relative to the delaying system (Barton *et al*., 1994). Furthermore, sleep was disrupted more in the advancing system between afternoon shifts, attributable to it being easier to delay sleep rather than advance it (Barton *et al*., 1994).

Cruz *et al.* (2002) reported that vigilance and complex task performance did not significantly differ between groups working clockwise or counter-clockwise schedules during a week-long testing scenario. However, performance did differ significantly according to the type of shift, in that morning and night shifts tended to result in performance decrements. De Valck *et al*. (2007) supported both of these observations, reporting that driving performance, which was assessed after each shift, did not differ between different shift rotation directions, but was worst following the night shift. However, subjective sleepiness was significantly higher during the counter clockwise or backward rotation. The authors attributed this to the observed negative effects that this direction of rotation has on the quality and quantity of recovery sleep, a conclusion supported by Hakola and Härmä (2001) and van Amelsvoort *et al*. (2004).

Lastly, advancing systems with quick returns were associated with worse outcomes than those without (Barton and Folkard, 1993). This observation lead these authors to stress that the concomitant effects of the length of the breaks between shifts should also be considered with respect to the overall impact of shift system on alertness and health (Barton and Folkard, 1993). This view was supported by Tucker *et al*. (2000), who did not find any significantly negative effects associated with advancing shift systems, but cautioned against ignoring the impact of quick returns that accompany anti-clockwise rotations.

Summary

Shifts that rotate in a forward or clockwise fashion are generally recommended from a circadian perspective. Furthermore, clockwise rotations limit quick returns, which have been associated with reduced recovery and increased sleepiness during subsequent shifts. However, in some cases, the type of shift and not the direction in which they rotate, elicit a greater impact on alertness and performance.

2.4.4.4 Shift start and end times

There is limited research surrounding the issue of shift timings (Kecklund and Åkerstedt, 1995). The time that a night shift starts and ends directly impacts the timing of the other shifts (that is, morning and evening shifts) in three-shift systems. It also impacts on how much sleep can be obtained prior to a morning shift or after a night shift (Kecklund and Åkserstedt, 1995). According to Knauth *et al*. (1980a) and Åkerstedt (1998), common shift start times are 06h00 (morning), 14h00 (afternoon) and 22h00 (night). If the morning shift is considered first, it is recommended that shifts not start too early to ensure that adequate sleep is obtained prior to starting work (Knauth *et al*., 1980a; Knauth, 1993; Folkard and Barton, 1993; Rosa *et al*., 1996). This stems from shift workers being unable to significantly advance their sleep due to the low sleep propensity between 20h00 and 22h00, described by Lavie (1986) as the forbidden zone for sleep. However, recommendations surrounding night and evening shift start times remain vague.

A later start for a morning shift (from 06h00 to 07h00) improved sleep length, quality and reduced sleepiness during the morning shift of shift workers in a steel rolling mill (Rosa *et al*., 1996). However, by design, this meant a later start time for both the evening and night shifts, which has effects on a number of factors. In contrast to the improvements in the morning shift following the change, the majority of measures were negatively impacted in both the evening and night shifts (Rosa *et al*, 1996). An increased number of lapses in the choice reaction time test during each shift after the schedule change were indicative of increased sleep disturbances associated with the change (Rosa *et al*., 1996). More generally, the shift schedule change was accompanied by complaints of increased interferences with domestic responsibilities (Rosa *et al*., 1996).

With respect to sleep length, Bjerner *et al*. (1948; as translated and cited in Rosa *et al*., 1996) found that when the shift changeover (between night and morning) was shifted from 04h00 to 05h00, the total amount of sleep decreased following the night shift (5.75 hrs to 5 hrs) and increased prior to the start of the morning one (6 hrs to 6.75 hrs). This reduced sleep following the night shift is attributable to the timing of sleep onset (Bjerner *et al*., 1948; Rosa *et al*., 1996): attempting to sleep during daylight hours results in curtailed sleep due to the alerting effects of the circadian clock (Czeisler *et al*., 1980; Åkerstedt *et al*, 1991).

In addition to this, observations of increased sleepiness during night shifts that ended late (after 07h00) have been made in truck drivers (Kecklund and Åkerstedt, 1993) and train operator (Torsvall, 1987). This stems largely from the combination of the time of day and the fact that by the early morning, night shift workers have been awake for an extended period of time, sometimes as long as 24 hours (Kecklund and Åkerstedt, 1995).

Summary

It seems reasonable that morning shifts should not start too early, so as to avoid difficulties in falling asleep during the preceding night. With respect to the night work, shifts should not start too late (between 22h00 and 00h00) and should end as early as possible, to ensure that post shift sleep is not disturbed by the alerting signals of the circadian rhythm and the pressures of a predominantly diurnally orientated society.

The above mentioned factors are most relevant for this thesis. However, for completeness, other considerations around ergonomics shift designs are reviewed in brief.

2.4.4.5 Limiting quick returns

Quick returns refer to short breaks (less than 11 hours) between the end of one type of shift and the start of another (Hakola *et al*. 2010; Vedaa *et al.,* 2015) that are usually part of backward rotating shift schedules (Barton and Folkard, 1993; Knauth, 1993).There appears to be consensus that quick returns, irrespective of which shifts workers rotate between, are associated with reduced sleep length (Axelsson *et al*.,

2004) and increased sleepiness during subsequent shifts (Tucker *et al*., 2000). This will have implications for alertness during subsequent shifts. These effects are likely to be exacerbated if shift workers have extended commutes (Tucker and Folkard, 2012). As such, at least 11 hours must be scheduled between shifts to ensure adequate recovery. Quick returns or limited time off between shifts and shift systems, with which they are associated, should be avoided (Kundi, 2003).

2.4.4.6 Extended shifts

In industries that require 24 hour operations, work time can be covered by either three, eight-hour shifts or two, 12-hour shifts (Axelsson, 2005). Extended shifts or compressed work weeks are popular in that they allow work to be covered more economically as fewer staff have to be employed (Hung, 1996). From a worker perspective, they limit the total number of working days and the need to commute, while enabling more rest days between duty periods (Rosa, 1995; Smith *et al*., 1998). Furthermore, extended shifts and the associated rest periods that follow allow for family and domestic roles to be fulfilled, fewer shift hand overs and decreased overtime (as reviewed in Knauth, 2007). However, extended shifts tend to result in extended time awake and time on task, which has been associated with increased risk (Folkard *et al*., 2003), particularly if this occurs during the night shift. Furthermore, they have also been associated with reduced recovery time between shifts, which will impact subsequent shift alertness (Rosa, 1991; Axelsson, 2005).

However, the evidence surrounding the effects of extended shifts on sleep, fatigue, health and performance remain equivocal, particularly in field studies (Knauth, 1993; Smith *et al*., 1998; Ferguson and Dawson, 2012). This is attributed mainly to the interaction of many different elements of a shift system (such as those included above) and task characteristics and how these impact on worker alertness during night shift work (Ferguson and Dawson, 2012). Although popular from the worker's perspective due to increased time off, shifts longer than 12 hours may present an increase risk of reduced alertness and performance and should therefore be avoided (Tucker and Folkard, 2012).

2.4.4.7 Other characteristics of shift systems

Decisions pertaining to whether a shift system is *continuous or discontinuous* are usually not driven by ergonomic factors, but economic ones (Tucker *et al*., 2000). However, there is some evidence to suggest that avoiding work on the weekends is associated with improved recovery and well-being (Fritz and Sonnetag, 2005), but the research in this area is limited. In a summation of relevant literature Åkerstedt *et al*. (2000) stressed that one *rest day* after a series of shifts is insufficient to facilitate recovery, and that at least two to four days off are more appropriate. These authors stress that more rest days should be afforded if a series of particularly extended shifts or night shifts have been completed. In line with this, some authors recommend not more than *six continuous days of work* (Knauth, 1996; Kundi, 2003; Spencer *et al,* 2006), with at least two days to recover. However, if working hours are extended, then the number of consecutive days should be reduced to limit cumulative fatigue (Tucker and Folkard, 2012). Lastly, the costs associated with arranging working time needs careful consideration, as employing extra shift workers to facilitate a more rapid rotation or shorter duty period may not be economically feasible.

2.4.5 Napping and shift work

In the context of shift work, the use of napping as a countermeasure has and is still receiving interest. According to Dinges *et al*. (1987) napping refers to a period of sleep that is half the duration of a normal sleep period (from minutes up to four hours). The practise of napping can take two forms with respect to shift work; prophylactic naps occur prior to the period of sleep loss (typically the afternoon before a night shift: for example Takahashi *et al*., 1998; Macchi *et* al., 2002; Gabarino *et al*., 2004; Lovato *et al*., 2009). These nap periods are practised by night shift workers to reduce sleep pressure prior to entering the night shift (Bonnet, 1991). Although important, this form of napping is beyond the scope of this thesis. On shift napping on the other hand may support the homeostatic and chronobiological need for sleep during a night shift and subsequently reduce decrements in alertness and performance.

Reactive or on shift naps have been researched using a vast array of methodologies, in that the length and timing of these naps has differed between studies (Matsumoto, 1981; Gillberg, 1984; Rogers *et al*., 1989; Bonnet and Arand, 1995; Takeyama *et al*., 2002; Takeyama *et al*., 2004; Schweitzer *et al*., 2006; Kubo *et al*., 2007; Lovato *et al*., 2009). Research has also purveyed a variety of fields. These include (among others) aviation, space flight, plant and/or service industries, air traffic controllers, medicine and various other transport sectors. The effects of naps have also been studied during continuous performance periods or sleep deprivation (eg: Haslam, 1985; Dinges *et al*., 1987; Dinges *et al*., 1988; reviewed in Naitoh and Angus, 1987; Bonnet, 1991).

2.4.5.1 Understanding the benefits of napping

Napping is common practice in a number of population groups and contexts: Takahashi (2003) argues that, young adults, the elderly, shift workers and individuals suffering from sleep disorders, for the most part experience positive clinical outcomes from napping. When included during actual shifts, naps have been associated with the reduction in physiological sleepiness and the inherent effects of sleep loss (Matsumoto and Harada, 1994), increased vigilance and alertness on shift (Muzet *et al*., 1995; Sallien *et al*., 1998; Davy and Göbel, 2013), decreased subjective sleepiness complaints (Smith-Coggins *et al*., 2006; Smith *et al.,* 2007; Lovato *et al*., 2009; Davy and Göbel, 2013) and sustained or improved performance during various cognitive / neurobehavioural measures (Matsumoto and Morita, 1987; Takahashi *et al*., 1999; Della Rocco *et al*., 2000; Takeyama *et al*., 2005; Phillip *et al*., 2006; Kubo *et al*., 2007; Smith *et al*., 2007; Roach *et al*., 2011).

On a more long term basis, Bonnefond *et al*. (2001) and Kubo *et al*. (2007) concluded that regular napping may aid in reducing the disruptions to both digestive and cardiovascular functions and improve well-being at work in general. Drake and Wright (2011) suggest that napping is an important means of managing the potential negative health effects of shift work, while Geiger-Brown and McPhaul (2011) emphasise napping’s role in improving safety. Despite the reported benefits, the inclusion of napping in work scheduling does present a number of practical and logistical challenges *in situ* which constitute additional reasons for why universal recommendations remain elusive. This stems mainly from the interaction of a number of factors that affect the efficacy and practicality of napping as a countermeasure. These include, but are not limited to, how long the nap is, where it can be taken, when it is taken in relation to the circadian phase, the extent of prior wakefulness, the timing of nap cessation, how “lost” working time is covered effectively and the impact of sleep inertia. These potential challenges are expanded upon initially. Thereafter, important considerations pertaining to nap length and timing and their interaction are discussed.

2.4.5.2 Potential challenges associated with napping implementation

Despite some of the established real world and laboratory-based benefits associated with napping, as a practise, it is sometimes marred by stigma. More specifically that sleeping at work is for the “lazy” (Takahashi, 2003). Furthermore, scheduling such rest periods can be logistically challenging (Takahashi, 2003): for example, determining whether napping is an appropriate and feasible countermeasure for a specific type of task. In safety critical work such as emergency medicine, performance could be negatively affected by napping (Ruggiero and Redeker, 2013). From an economic perspective, the inclusion of napping requires that workers be absent from work, which has implications for productivity and safety. Additionally, finding a safe (Purnell *et al*., 2002) and appropriate place to sleep (Oriyama *et al*., 2014) is of critical importance. Furthermore, the length and quality of post shift recovery sleep can be negatively affected by the inclusion of on shift napping (Matsumoto and Harada, 1994; Sallinen *et al*., 1998; Bonnefond *et al*., 2001). Lastly, one of the most significant challenges to napping is the effect that the post sleep grogginess or sleep inertia has on alertness and performance (Muzet *et al*., 1995; Hofer-Tingeuley *et al*., 2005; Scheer *et al*., 2008; for review see Tassi and Muzet, 2000).

2.4.5.2.1 Sleep inertia

Referred to historically as sleep drunkenness or disorientation, sleep inertia (SI) (Lubin *et al*., 1976) describes the period of hypovigilance that is present upon awakening from sleep (reviewed in Tassi and Muzet, 2000). Despite extensive research into understanding the phenomenon, there is still little consensus as to how long sleep inertia lasts once an individual is awake. Previous research has reported its effects not lasting longer than 10 – 15 minutes (Tassi *et al*., 1992), but this was following a one-hour nap. Other studies have reported durations of 20 to 30 minutes for this phase of decreased alertness and performance (Achermann *et al*., 1995; Bruck and Pisani, 1999; Wertz *et al*., 2006; Lovato *et al*., 2009; Signal *et al*., 2012). Jewett *et al*. (1999) concluded that sleep inertia was still evident in both subjective and objective measures two to four hours after awakening. This inconsistency may arise from a variety of factors, such as whether performance post wake up returns to pre-sleep levels or whether it levels off, regardless of the performance level prior to sleep.

Jewett *et al*. (1999) and Tassi and Muzet (2000) found that different neurobehaviorual measures are also more sensitive to sleep inertia than others. Rather simple tasks reflect sleep inertia to a larger extent than more complex ones (Tassi and Muzet, 2000). Naitoh and Angus (1987) add that performance speed, rather than accuracy is more sensitive to sleep inertia. Jewett *et al*. (1999), Kubo *et al*. (2010), Signal *et al*. (2012), Tremaine *et al*. (2010) and Williamson and Friswell (2011) also emphasised a disparity between the effects of sleep inertia on subjective measures when compared to objective ones. In brief, these studies found that perceptions of sleepiness tend to recover faster than objective measures. This may mean that individuals under these circumstances may overestimate their ability to perform.

Irrespective of the time it takes for sleep inertia to dissipate, there is agreement that it's intensity (and by definition its effects on post sleep alertness and performance) is mediated by a number of different, interacting factors. These include, but are not limited to the length of prior wakefulness (Balkin and Badia, 1988), the length of the nap (Takahashi *et al*., 1999; Brooks and Lack, 2006; Kubo *et al*., 2010; Mulrine *et al*., 2012), the sleep phase during which waking occurs (Dinges *et al*., 1985) and awakening during the nadir of body temperature (Dinges *et al*., 1985; Scheer *et al*., 2008). With respect to the last point, the down regulation of body temperature that accompanies sleep is theorised to be one reason for the presence of sleep inertia; this process is implicated in the down regulation of cerebral metabolism, which in turn affects alertness and performance (Dinges, 1990).

In light of these challenges, previous research has suggested that the provision of a buffer period immediately after awakening be considered to avoid the presence of sleep inertia interfering with performance post nap (Scheer *et al*., 2008; Kubo *et al*., 2010; Signal *et al*., 2012). Van Dongen *et al.* (2001) recommend the use of caffeine to limit the effects of sleep inertia post nap. This stems from the antagonistic effects that caffeine has on receptors for adenosine, a substrate that is purported to drive the homeostatic need for sleep. Such considerations are critical when researching or implementing napping as a countermeasure during a night shift.

2.4.5.3 Considerations for nap length

Lovato and Lack (2010) posit that, irrespective of a nap's length (minutes to hours), some benefits to alertness and cognitive performance do manifest upon awakening. Brooks and Lack (2006) suggested that 30 minutes would be an adequate nap length, as anything longer would result in deeper sleep and an increased risk of sleep inertia post wake up, an assertion supported by Tietzel and Lack (2002). Brooks and Lack (2006) demonstrated that the benefits of a nap with respect to waking performance were dependent upon length: shorter naps produced immediate improvements (10mins) while longer naps (20 or 30 minutes) lead to sleep inertia before the benefits manifest. Howard *et al*. (2010) and Lovato *et al*. (2009) added that naps longer than 30 minutes are also impractical. Shorter naps of 20 to 30 minutes are also in line with the break schedules of most shift workers and will therefore not interfere with work processes (Purnell *et al*., 2002; Oriyama *et al*., 2014).

However, in situations that require prolonged or continuous work periods, a longer nap may be more beneficial, considering that the benefits of sleep length (post wake up) are dose dependent, particularly with respect to cognitive performance (Dinges *et al*., 1987; Bonnet, 1991; Van Dongen *et al*., 2003a; Belenky *et al*., 2003). Furthermore, researchers agree that nap length is dependent on the length of shift (Sakai and Kogi, 1986, as cited in Takeyama *et al.,* 2005) and the length of the break opportunity provided. In most instances, a long nap (>120minutes) is not practical. However, Minors and Waterhouse (1983) reported that a 4-hour sleep taken at the same time of the day (referred to as an anchor sleep) stabilised the circadian rhythm, even when the other 4 hours (of the typical 8-hour sleep recommendation per day) was obtained at any other time of the day. Although greater benefits (in terms of the resulting alertness and performance) can be realised from nap/sleep periods that are longer than 120 minutes (Bonnet, 1991), the effects of sleep inertia need to be considered and managed in the context of work.

2.4.5.3.1 Relevant laboratory investigations on the effects of nap length

A 30-minute nap, scheduled between 02h00 and 03h00 during the first night shift significantly improved reaction and subjective sleepiness in a group of medical scientists and nurses (Smith *et al*., 2007). The benefits of nap were realised immediately for the subjective sleepiness, but were delayed (by roughly 60 minutes) for the performance measures (Smith *et al*., 2007). This was likely the effect of sleep inertia. Lovato *et al*. (2009) researched a combination of a 2-hour prophylactic afternoon nap (15h00 to17h00) and a 30 minute nap starting at 02h30 compared to a no nap condition during a single night of wakefulness. Cognitive performance (short term memory), mean number of lapses during the psychomotor vigilance task and subjective sleepiness significantly improved following the nap at 02h30. As was the case in the study by Smith *et al*. (2007), subjective sleepiness measures responded to the nap sooner than the more objective measures, even after a significant decline immediately after the nap, which Lovato *et al*. (2009) attributed to sleep inertia.

Over the course of one night shift, Rogers *et al*. (1989) concluded that a 1-hour nap taken at 02h00 was insufficient to attenuate decrements in a host of neurobehavioural measures (reaction time, auditory, complex and visual vigilance task performance, short term memory, logic and cognitive throughput). Takeyama *et al*. (2002) on the other hand studied the effects of a 2-hour nap (between 02h00 and 04h00) over three consecutive night shifts. Improvements were observed in 3-choice reaction and reduced subjective complaints for morning types (MT), but only during the first night. During subsequent night shifts, the nap elicited no effect for either chronotype relative to the no nap condition. This was accounted for by the fact that the MT would have been awake for longer than the evening types (ET) on the day before the first night shifts; extended wakefulness may have resulted in better quality sleep during the nap on the first night, relative to the second and third shifts. The study however did not include measures to track sleep quality. Daytime sleep, in this case was also unaffected by the nap for both chronotypes (Takeyama *et al*., 2002).

2.4.5.3.2 Relevant field-based investigations on the effects of nap length

Lane deviations during a 200 km drive between the hours of 02h00 and 03h30 were significantly reduced, following a 30-minute nap taken at 01h00 relative to the no nap group (Phillip *et al*., 2006). Furthermore, the nap also significantly reduced feelings of subjective fatigue during the night drive compared to the no nap (Phillip *et al*., 2006). Similarly, Sagaspe *et al.* (2007) also reported a decrease in inappropriate lane crossings during a 200 km drive (between 02h00 and 03h30) following a nap of 30 minutes taken at 01h00. In contrast to the Philip *et al*. (2006) study, subjective sleepiness was not reduced following the nap. In the context of aviation, Valk and Simons (1998) measured the effects of a flexible 40-minute nap opportunity during various in and out bound transmeridian flights on tracking performance and subjective sleepiness. The inclusion of the nap, taken during the cruising part of the flight, significantly reduced subjective sleepiness and improved tracking performance in pilots that napped, relative to those that did not. Furthermore, subjective sleepiness ratings were significantly reduced amongst pilots who perceived to have actually slept, relative to those that did not (Valk and Simons, 1998). Similarly, Rosekind *et al*. (1994b) studied a 40-minute nap opportunity for crew members during a number of 9-hour trans-Pacific flights. Napping occurred during 93% of the scheduled opportunities, with the average length being 25.8 minutes. This translated into improvements in vigilance performance, fewer decrements in median reaction time and fewer lapses as compared to the no nap group (Rosekind *et al*., 1994)b.

Over the course of three consecutive night shifts Smith-Coggins *et al*. (2006) monitored psychomotor vigilance task and probed memory recall performance as well as subjective sleepiness for a group of 49 emergency department physicians. During the third night, participants were randomly allocated to a nap or no nap group. A napping opportunity of 40 minutes was afforded to the nap group between 03h00 and 04h00. The nap culminated in decreased reaction time and fewer lapses, which was accompanied by significantly lower subjective sleepiness at the end of the shift

(07h30). Memory performance decreased immediately following the nap as a result of sleep inertia, but improved by the end of the shift (Smith Coggins *et al*., 2006).

Bonnefond and colleagues (2001) implemented and monitored the effects of a one-hour nap opportunity (to occur between 23h30 and 03h30) on sleep, satisfaction and general wellbeing of industrial plant workers. Over the course of the year, main sleep (after the night shift) was not significantly reduced, while feelings of adaptation tended to improve with time. Workers reported sleeping an average of 31 minutes during the one-hour opportunity, which aided in improving the ability to stay awake during the night shift (Bonnefond *et al*., 2001).

2.4.5.4 Considerations for nap timing

Caldwell (2002) stressed the importance of ensuring that the timing of the nap with respect to the circadian phase be considered carefully. More specifically, she referred to how the timing of the nap would impact the ease of falling asleep, of staying asleep and the impact the sleep during the nap will have on alertness upon waking. The individual need for sleep with respect to the timing of the sleep onset is an additional factor that has also been considered (Davy and Göbel, 2013). A number of researchers (Matsumoto, 1981; Dinges *et al*., 1987; Åkerstedt and Folkard, 1997; Caldwell, 2002) agree that nap sleep, irrespective of its length, is easiest to initiate and maintain near to the nadir, which is around 03h00 to 06h00. The benefits associated with waking from a nap during this period do however differ between studies. This stems from the fact that naps scheduled during the nadir are the hardest from which to waken, and that sleep inertia will likely affect post nap alertness and performance (Dinges *et al*., 1988; Lovato and Lack, 2010). The interaction between circadian timing of the nap and its length will also determine the extent of post nap sleep inertia.

2.4.5.4.1 Relevant laboratory-based investigations on the effects of nap timing

Gillberg (1984) explored the effects of two, 1-hour naps taken at 21h00 and 04h30. He found that the later nap was superior in that subjective sleepiness and choice reaction time performance were better than that of the early nap and no nap conditions. The better performance and sleepiness responses that resulted from the later nap were due to its proximity to the nadir (Gillberg, 1984), at which sleep and chronobiological pressure would have been highest. This is supported by Hartley (1974) and Bonnet and Arand (1995) who concluded that naps taken during the night improved performance as they were more proximally located to the periods during which sleepiness would be high, as compared to an afternoon (prophylactic) nap. Additionally, Gillberg (1984) concluded that 21h00 may have been too early for the onset of sleep, a conclusion supported by the observations of previous researchers (Lavie, 1986).

Matsumoto's (1981) evaluation of 2-hour naps taken at 22h00, 02h00, 04h00 and 06h00 found that sleep taken at 04h00 and 06h00 was rated subjectively better quality than that taken at 22h00. Takeyama *et al*. (2004) found no significant differences in vigilance task performance, choice reaction time and subjective drowsiness measures following 1 and 2 hour naps taken at either 00h00 or 04h00. There was however, a significant reduction in reaction time performance following the late 1-hour nap, which the authors attributed to sleep inertia, the severity of which is said to be higher the closer one wakes to the nadir (Naitoh and Angus, 1987; Naitoh *et al*., 1993). Contrary to this, Howard *et al*. (2010) reported that this relationship (between circadian timing of a nap and the presence of sleep inertia) has not fully been determined yet. In their comparison of a 30-minute nap opportunity at either 20h15 or 04h00, relative to a no nap condition, they reported shorter sleep latencies and longer sleep lengths in the later nap. However, despite this, reaction time and subjective sleepiness significantly increased over the course of the night (time effect) and there were no significant effects or differences between the nap conditions.

Kubo *et al*. (2007), in a very similar set up to Takeyama *et al*. (2004), found no observable differences in psychomotor performance between the different nap timings, attributable to minimal 2 to 3-hour difference in their timing. However, there was a significant reduction in subjective fatigue perceptions during the later naps relative to earlier ones (Kubo *et al*., 2007). These observations lead to the conclusion that, in night shift settings, later and longer naps are more appropriate for maintaining early morning performance, provided that measures to counteract the ensuing sleep inertia are implemented. In a follow up study that addressed the degree of sleep inertia present following different nap times and lengths, Kubo *et al*.,

(2010) concluded that care should be taken when a nap of 60 minutes occurs during the early morning (between 04h00 and 05h00). These authors observed a decrement in performance (reaction time and lapses during a vigilance task) but not in subjective sleepiness following a 60-minute nap taken at 04h00 when compared to a no nap condition (Kubo *et al*., 2010). This was attributed to the presence of sleep inertia due to a higher percentage of slow wave sleep relative to a 120-minute nap taken at the same time.

Using experienced shift workers in a laboratory setup, Sallinen *et al*. (1998) compared the effects of two different length naps (30 minutes and 50 minutes) at two different times (01h00 and 04h00) on reaction time, subjective sleepiness measures and the day time sleep during the first night shift. All nap conditions reduced the decrements in reaction time measures as compared to the no nap condition, but did not have any effect on subjective sleepiness. This led to the conclusions that the early and late naps, irrespective of their length, were equally beneficial in reducing behavioural sleepiness (Sallinen *et al*., 1998). This finding contradicts that of Gillberg (1984) and Kubo *et al*. (2007), but could be accounted for by the fact that the participants in the study were regular shift workers and had slept normally on the two nights prior to the experiments.

2.4.5.4.2 Relevant field-based investigations on the effects of nap timing

Purnell and colleagues (2002) explored the potential differences between 20-minute naps taken at either 01h00 or 03h00 to a no nap group during two 12-hour night shifts that made up a weekly rotating schedule in air craft maintenance engineers. Questionnaires and a performance test battery, consisting of a subjective fatigue scale, two simple reaction time tests and a vigilance test were used to monitor the effects of the experimental conditions (Purnell *et al*., 2002). Performance was significantly better during a vigilance task for both nap conditions as compared to the no nap group. Simple reaction time performance, as well as subjective fatigue ratings did not differ between either of the nap conditions or the control group. This is possibly attributable to the potentially insensitive, short duration reaction time test and the lingering effects of sleep inertia following the nap respectively. Similarly, neither nap condition elicited any additional reductions in day time recovery sleep, relative to the control group (Purnell *et al*., 2002).

Signal *et al*. (2009) reported that a 40-minute nap, taken either at 00h20 or 02h20 (dependent on the shift start times) resulted in improvements in reaction time relative to a no nap group in air traffic controllers. Further, there were no performance differences between the two nap timings either. Lastly, sleep following each shift was unaffected by either nap, but sleep began earlier and lasted longer following the earlier nap**.**

2.4.5.5 Other nap strategies: Split sleep wake and poly phasic sleep schedules

Another strategy to improve the total amount of sleep obtained per day amongst a shift working population is the use of split sleep wake or poly phasic sleep schedules, particularly during extended duty periods (Minors and Waterhouse, 1983; Porcu *et al*., 1998; Jackson *et al*., 2014; Belenky *et al*., 2015; reviewed in Ficca *et al*., 2010). These refer to two or more periods of sleep during a day, as opposed to the typically monophasic, consolidated sleep period (McDonald, 2013; Shea *et al*., 2014; Jackson *et al*., 2014; Belenky *et al*., 2015). Such sleep arrangements are evident in medical settings, railway and marine watch systems all of which are typified by extended and alternating periods of work (for a review, see Short *et al*., 2015, as such extended work periods are beyond the scope of this thesis).

Sleep obtained following the completion of a night shift is typically curtailed (by between two to four hours) due to the combination of alerting effects of the circadian system and the competing social and domestic responsibilities (Åkerstedt *et al*., 1991; Holmes *et al*., 2001; Davy and Göbel., 2013). This reduction in the total amount of sleep obtained in 24 hours results in the development of sleep debt, which negatively affects subsequent alertness and performance (Van Dongen *et al*., 2003b). Supplementing this already curtailed day sleep with an additional sleep period at night increases the total sleep obtained, which according to Belenky *et al*. (2015) is the critical factor in the maintenance of performance when a consolidated sleep period is not achievable.

2.4.5.5.1 Laboratory-based studies on the effects of split sleep wake schedules

Mollicone and colleagues (2008) investigated the effects of differing degrees of restricted sleep at night with varying lengths of supplementary day time naps on reaction time and lapses, cognitive throughput and subjective sleepiness. The design included the use of the anchor sleep, a shortened period of sleep that is scheduled at the same time of the day, the effects of which are supplemented by an additional nap (Minors and Waterhouse, 1983). To avoid the confounding effects of circadian phase and prior wakefulness, outcome measures were analysed as a daily average performance. In all measures, responses were dependent on total time in bed. This means that the less sleep an individual had, the worse their performance and higher their sleepiness (Mollicone *et al*., 2008).

Jackson *et al*. (2014) compared the effects of splitting a 10-hour sleep period into two times of the day (03h00 – 08h00 and 15h00 to 20h00), with a consolidated night time (22h00 – 08h00) and day time sleep (10h00 – 20h00). The study spanned five days and occurred in a laboratory setting. Total sleep was significantly longer in the night sleep group, when compared to the other two groups. However, the split sleep group also slept longer when compared to the day sleep group. No significant differences with respect to cognitive throughput or psychomotor vigilance performance were observed, but subjective sleepiness was significantly lower in both the consolidated night sleep and split sleep groups, relative to the day sleep group.

Following a 2-hour afternoon prophylactic nap (14h00) prior to an on shift 30-minute nap (at 03h00) Tremaine *et al*. (2010) reported that decrements in short term memory and reaction time performance and subjective sleepiness were ameliorated by the nap inclusion. Despite a reduction in both parameters immediately after the nap, attributable to sleep inertia, the decline in the measures was less pronounced when compared to the no nap condition (Tremaine *et al*., 2010). A further observation made by these authors and others (Kubo *et al*., 2010; Signal *et al*., 2012; Zhou *et al*., 2012) relates to the mismatch between subjective measures and performance measures, particularly measures that are novel, interesting or motivate the individual (Tremaine *et al*., 2010). This observation lead the authors to caution against relying too heavily on subjective ratings as an indicator of the risk of falling asleep in tasks that are motivating in nature, as it may not reflect the true level of sleepiness.

2.4.5.5.2 Relevant field-based investigations on split wake schedules

In medical settings, split sleep wake schedules are common and take the form of what is referred to as a protected sleep or nap period (PSPs). Although the exact definition of this can vary according to the length and timing of the protected sleep period, a common feature of these interventions is the fact that the sleep is covered by additional staff. These protected sleeps are also set to occur during extended night shifts in order to limit the extended wakefulness and any alertness decrements that may ensue (Arora *et al*., 2006; Volpp *et al*., 2012; Shea *et al*., 2014). The key motivation behind the inclusion of these PSPs has to do with the fact that, although they cannot limit the cumulative effects of night work, they provide an opportunity for night shift workers to obtain decent sleep at the appropriate time of day during extended shifts (Shea *et al*., 2014).

Volpp *et al*., (2012) reported improved alertness both objectively and subjectively and less on call nights with no sleep following the inclusion of a five-hour protected sleep between 00h30 and 05h30 in the hospital context during a 30-hour work shift. This was compared to a group that did not nap during the 30-hour duty period. Shea *et al*. (2014), following the inclusion of a three-hour protected nap opportunity, reported similar improvements in psychomotor performance but not in sleepiness ratings as compared to participants who didn’t nap during a shift of up to 30 hours in length. This was consistent with participants that napped between 00h00 and 03h00 or 03h00 to 06h00. In contrast, reductions in subjective fatigue (while on call and post call) and an increase in total sleep duration were reported by Arora et al. (2006); this study compared the effects of a protected sleep period between 00h00 and 07h00 to a standard night shift arrangement (no naps) for a group of medical interns. However, an unwillingness to “hand over” care of their patients to other staff limited the use of the protected sleep by a large proportion of the intern group (Arora *et al*., 2006).

2.5 ASSESING THE EFFECTS OF NIGHT SHIFT WORK AND FATIGUE

Fatigue in the context of night shift work can arise from the interaction of a number of individual-specific, biological, psychological and task/work-related factors. Owing to these complex interactions, a number of authors (Bartlett, 1943; Grandjean, 1979; Aaronson *et al*., 1999) argue that, to measure the effects of fatigue from one perspective or one set of measures is futile and grossly underestimates the complexity associated with this phenomenon. Furthermore, if the various definitions of fatigue are considered, then appropriate cognitive/mental, subjective and physiological measures should be incorporated into any testing scenario. In doing so, a relatively holistic perspective of how working arrangements, such as night shift work, affect an individual's ability perform can be obtained

2.5.1 Performance measures

In both in situ and laboratory settings, a variety of measures that have been adopted to provide some indication of the effects of sleep loss / deprivation (Dawson and Reid, 1997; Lamond and Dawson, 1999; Van Dongen *et al*., 2003a; Balkin *et* al., 2004; reviewed in Rogers *et al*., 2003), time of day / circadian effects (reviewed in Carrier and Monk, 2000; Blatter and Cajochen, 2007; Valdez *et al*., 2008; Goel *et al*., 2013) and general fatigue (Valdez *et al*., 2005). Although the ecological validity of such tests and the controlled laboratory contexts in which they are applied is not always representative of normal workplace and task performance requirements (Takahashi, 2014), understanding the effects of night shift work on aspects of neurobehavioral functioning is critical.

These tests, of which there are many, are designed to assess the effects of certain experimental conditions (such as sleep loss or circadian phase) on different parts of human information processing, as encapsulated, for example in the model proposed by Wickens (1984). Wickens and Carswell (1997) hold that human information processing lies at the "heart" of understanding human performance. It facilitates the exploration of how different conditions, such as fatigue, affect the efficiency with which this information is processed (Meijman, 1997). Although this and other models provide a solid basis upon which to conceive of how human information processing occurs, they tend to overly simplify the complex neural structures and processes involved.

2.5.1.1 Human information processing (HIP)

Effectively HIP can be viewed as a filtering process, during which key pieces of information from the environment assist in the selection and initiation of appropriate actions in response to what has been perceived. The model proposed by Wickens (1984) encapsulates this process by dividing it into separate, but sequential stages, all of which require time and attentional resources to complete (Figure 3) . These include sensory processing through the short term sensory store, perception, decision making and memory, followed by response selection and execution.

Briefly, information from the surrounding environment is initially received by various sense receptors (visual, auditory, tactile and kinaesthetic). Importantly, the quality and quantity of this information will affect any subsequent information processing, emphasising the importance of these sense organs (Wickens, 1984). This information is then stored temporarily by what Wickens refers to as each sensory system's "central mechanism". More specifically, this short term sensory store maintains a brief representation of the information received, which is relatively accurate with respect to the detail, doesn't require conscious attention but decays rapidly (Wickens, 1984).

Thereafter relevant information is processed at higher levels of the nervous system; more specifically, the information is matched to previously stored or learned material which takes the form of neural codes. This enables the new information to be recognised or perceived and categorically assigned to the relevant repository in the long term memory store (Figure 3), hence the link between perception and long term memory (Wickens, 1984). The process of categorisation is directly impacted by the complexity of the information received; determination of the presence of a stimulus (or its detection, such as the case would be in a simple reaction time task) does not involve the need to recognise, identify and categorize new information (as would be the case in pattern recognition task) (Wickens, 1984).

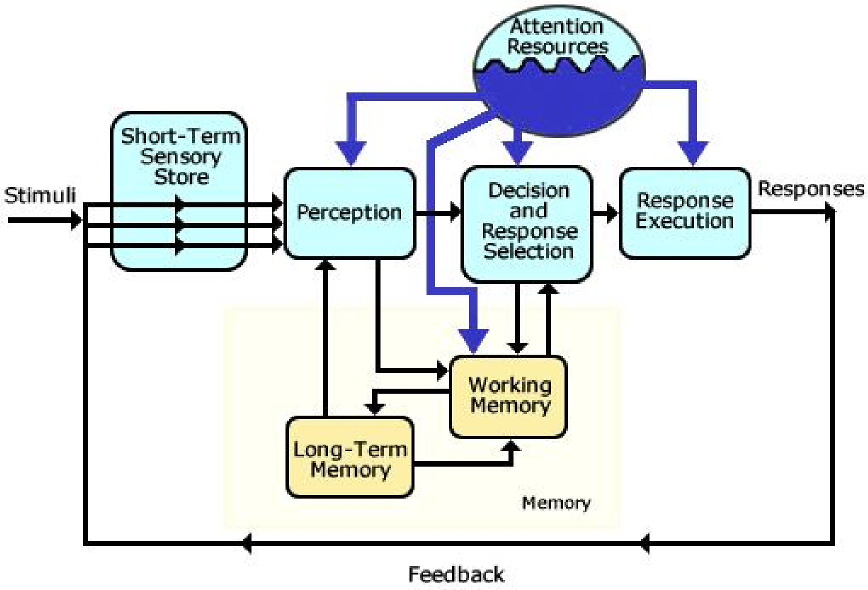

Figure 3: A model of human information processing (Adapted from Wickens, 1984).

Following this perception, a decision making process is initiated in order to select an appropriate response. In this stage, referred to as cognition, a decision is made relatively instantaneously and a response is selected and initiated (Wickens, 1984). Alternatively, the information is committed to memory, either for permanent storage or until an appropriate decision is made in conjunction with previous experiences (stored in the long term memory). Once a decision about the appropriate response has been selected, the separate and complex process of initiating and executing appropriately timed muscle contractions can occur (Wickens, 1984).

Finally, the consequence of the decision and response execution is derived via visual, haptic, auditory feedback, which can be used to either signify that the outcome was desirable or to modify future responses to ensure the intended outcome (Wickens, 1984).

The human information processing model allows for the systematic investigation of the different stages through which information from the environment must travel, be processed and transformed. In order to understand observed changes in the efficiency of different stages, it is pertinent to review (briefly) relevant theories that explain why these changes might occur. Thereafter, relevant outcome measures are reviewed.

2.5.1.2 Theoretical concepts to understanding the effects of fatigue on information processing

In order for information processing to occur, "attentional/energetic resources" are critical. These refer to internally-located inputs that are limited in number, but essential for effective processing. The work of Moray (1967: as cited in Wickens, 1984) and Kahneman (1973) present the idea that attentional resources are finite. As demand for these increases, either as a result of increased task demands or the onset of fatigue, these resources are depleted over time. This is hypothesized to contribute to decrements in performance.

Other theories portray decrements in HIP as a mechanism related to the regulation of the effort required to meet the demands of the task (Hancock and Warm, 2003; Hockey, 1997). In this context, continuous performance of a stressful task results in either a down regulation of effort in order to avoid fatigue or an increased effort to maintain task performance, which results in high levels of strain and the risk of premature fatigue onset (Hockey, 1997). The characteristics of the task, the inherent interest it engenders in the individual and levels of motivation also affect the allocation of resources and effort and consequently the development of fatigue.

The construct of fatigue is further explained by other broader theories related to how sleep deprivation and sleep restriction affect performance (Lim and Dinges, 2008). The *Lapse hypothesis* (Williams *et al*., 1959) held that, under conditions in which sleep loss occurs, short intrusions of sleep or periods of reduced arousal occur in the form of "microsleeps". These occurrences result in lapses in performance, where stimuli are missed during tasks such as the Psychomotor Vigilance task. Although initially attractive, this theory has been criticised for being unable to account for the variability in performance that accompanies sleep deprivation (as discussed in Doran *et al*., 2001 and Blatter and Cajochen, 2007). To account for this factor, Doran and colleagues (2001) proposed the *state instability hypothesis*, which explains how performance under sleep deprivation conditions, is accompanied not only by lapses, but increasing performance variability. Proponents of this approach explain that this variability arises from the increasing dysregulation between circadian and homeostatic factors under sleep deprivation and the effects of extended time of task

(Doran *et al*., 2001). These factors contribute not only to errors of omission, but also to errors of commission, which is believed to reflect the increasing compensatory effort to counter the abovementioned effects (Doran *et al*., 2001).

Pilcher *et al*. (2007) proposed the *controlled attention hypothesis*, which purports that sleep loss/deprivation/restriction affects performance during monotonous and uninteresting tasks, more so than tasks that are more inherently interesting or challenging to the operator. More specifically, these authors emphasise that tasks which require individuals to be more attentive, will be least affected by sleep loss (Pilcher *et al*., 2007). Other researchers have extended this theory to include the negative effects that increased sleep pressure / sleep deprivation (that accompanies work at night) has on vigilant and sustained attention and subsequent performance (Doran *et al*., 2001).

2.5.1.3 Visual perceptual tasks

2.5.1.3.1 Reaction time measures

In all forms of fatigue and sleep deprivation research, reaction time (RT) is one of the most commonly applied measures for behavioural alertness and attention. These tests can either require a participant to respond to one stimulus (referred to as simple RT with minimal decision making required) or one of multiple stimuli (termed choice RT where ruled-based decision making and therefore cognition is required). Additionally, stimuli to respond can be delivered through either visual or auditory signals. Indeed, RT measures have proved to be sensitive to sleep deprivation (Doran *et al*., 2001; Van Dongen *et al*., 2003a), sleep restriction (Dinges *et al*., 1997; Belenky *et al*., 2003) and the dual impact of sleep loss and time of day as a result of simulated (Gillberg, 1984; Lamond *et al*., 2004; Davy and Göbel, 2013) and real shift work settings (Ferguson *et al*., 2012a) in that response speed typically slows. Such measures reflect the extent of the cognitive slowing (Durmer and Dinges, 2005). However, owing to the simplicity of reaction time measures that represent the sum of perceptual, central and motor processing time, performance can be masked by motivation and arousal, even under instances of extended sleep deprivation.

2.5.1.4 Visual search tasks

Visual search tasks require participants to identify a target on a display amongst a number of distractor items and respond to it (Santhi *et al*., 2007). As with reaction time measures there tends to be an overlap between the perceptual and cognitive components of information processing. This is however dependent upon the nature of the task. More specifically, this refers to whether a task is merely one that requires participants to respond to one or two stimuli or multiple stimuli, which requires the involvement of memory and decision making. The completion of this task necessitates general and selective attention, which is known to be negatively affected by sleep loss (Doran *et al*., 2001; Santhi *et al*., 2007). Extensive research has determined that visual search tasks reflect the effects of time of day (Folkard *et al*., 1976; Cassegrande *et al*., 1997; Monk *et al*., 1997), circadian disruption (Suvanto *et al*., 1993) and sleep loss of varying degrees (Rogers *et al*., 1989; Cassegrande *et al*., 1997; de Gennaro *et al*., 2001).

2.5.1.5 Cognitive tasks

In brief, cognitive tasks require attention or vigilance and perception in order for the more cognitive processes (memory and decision making) to be engaged. Such tasks can include pattern recognition and substitution / cancellation tasks, decision making, memory, grammatical and logical reasoning tasks and arithmetic tasks (Curcio *et al*., 2001). For the purposes of this thesis, memory will be focused on, and not decision making.

2.5.1.5.1 Memory: working memory

Working memory (WM) as the ability to remember and use perceived information over a short period of time (Schmidt *et al*., 2007). The retention and manipulation of sensory information also requires individuals to be attentive and focused (Conway *et al*., 2005). Effective working memory is critical, considering its role in other cognitive functions such as decision making, reasoning and dual task performance (Kurtz, 2006). It is therefore pertinent that an understanding of the factors that affect working memory are considered.

Measures of working memory (which is sometimes used synonymously with short term memory) have been shown to mirror changes in body temperature (Folkard *et al*., 1976; Maury and Queinnec, 1993; Monk *et* al., 1997; Wright *et al*., 2002; West *et al*., 2002). Johnson *et al*. (1992) reported similar findings under conditions of forced desychnronisation, in that short term memory performance tended to mirror changes in core body temperature. In contrast, Wyatt *et al*. (1999), who reported that memory performance did not follow changes in body temperature, but was negatively affected by extended wakefulness.

In a month long study in medical residents, Gohar *et al.* (2009) reported that extended shifts and the resultant sleep loss negatively affected WM. This was attributed mainly to the effects of cumulative sleep debt experienced during the study. Additionally, under conditions of extended wakefulness (Wyatt *et al*., 1999), mild sleep deprivation (Polzella, 1975; Smith *et al*., 2002) and extended sleep deprivation (Turner *et al*., 2007). In addition, night shift work and sleep inertia has also been reported to result in decrements in working memory (Smith-Coggins *et al*., 2006).

2.5.1.6 Response execution / Motor output tasks

The motor response element of the information processing chain involves the actual initiation and execution of a desired response in response to a stimulus (during a task such as tapping task: Fitts, 1954). Alternatively, it refers to tasks that require constant motor control, as would be the case during a simulated driving or tracking task. Under the effects of time of day and conditions of sleep deprivation, tracking task performance has been impaired (Dawson and Reid, 1997; Lamond and Dawson, 1999; Bohnen and Gaillard, 1994; Åkerstedt *et al*., 2005; Phillip *et al*., 2005; De Valck *et* al., 2007). Similarly, others have found an increase in response time during a modified tapping task under simulated (Davy and Göbel, 2013) and real night shift conditions (Huysamen, 2014).

2.5.2 Physiological measures

2.5.2.1 Body temperature measures

Measures of body temperature have been used extensively as a marker of circadian rhythmicity in sleep and shift work research (Knauth and Rutenfranz, 1976; Folkard and Monk, 1980; Knauth *et al*., 1981; Aschoff, 1983; Härma *et al*., 1994; Monk *et al.*, 1997; Wyatt *e* al., 1999; Wright *et al*., 2002; Zhou *et al*., 2012). More specifically, during the habitual night, temperature measures decrease with the onset of sleep, typically reaching a minimum between 03h00 and 05h00 (Aschoff, 1983; Lack and Lushington, 1996). In the context of night shift work when sleep is unobtainable, reductions in body temperature still occur. This reduction in physiological arousal is problematic, given the fact that reductions in temperature have repeatedly been associated with, but not causative of, decrements in alertness, neurobehavioural performance and perceptions of fatigue or sleepiness (eg: Johnson *et al.*, 1992; Dijk *et al*., 1992; Monk and Carrier, 1998; Monk *et al*., 1997; Wright *et al*., 2002).

2.5.2.1.1 Body temperature and its relationship with alertness and performance

This relationship originated from pioneering work of Kleitman, who established what was thought to be a temporal link between the fluctuation in body temperature and changes in the performance of simple tasks such as card sorting, mirror drawing and multiplication speed. However, subsequent research has shown that these cyclical changes in task performance are influenced by a number of factors over and above circadian rhythmicity. These include the effects of the homeostatic sleep process (Dijk *et al*., 1992); the nature (self vs experimenter-paced) and demands of the task (complexity; discussed in Blatter and Cajochen, 2007), individual differences, such as chronotype, age and sex (Blatter *et al*., 2006), individual sleep need and personality (reviewed in Van Dongen *et al*., 2005) and changes in strategy to complete the task (discussed in Carrier and Monk, 2000).

Furthermore, the circadian rhythm of body temperature is also subject to masking effects, in that certain endogenous and exogenous mechanisms such as food intake, motivation, postural changes, environmental factors, ambient light levels, physical activity, sleep and noise will alter body temperature (as discussed in Van Dongen and Dinges, 2005). As a result, early researchers tended to overestimate the effects of or the relationship between, temperature changes and performance, as well as the degree of “adaptation” to night shift work (Härma 1995). Other research has used temperature measures to determine phase changes as a result of interventions such bright light exposure (Czeilser *et al*., 1990; Boivin and James, 2002) as well. [2]

2.5.2.2 Heart rate frequency and heart rate variability (HRV)

Heart rate frequency (HR) and heart rate variability (HRV) are non-invasive means of assessing autonomic balance over time (Massin *et al*., 2000) and the effects of working activities and conditions such as night shift work (Furlan *et al*., 2000; van Amelsvoort *et al*., 2004; Su *et al*., 2008; Dutheil *et al*., 2012; Wehrens *et al*., 2012). Heart rate frequency generally increases with physical activity (Jorna, 1992). Measures also reflect circadian-modulated up and down regulation, in that at night, measures are lower than during the day time (Furlan *et al*., 1990; Takahashi *et al*., 1999; Furlan *et al*., 2000; Dutheil *et al*., 2012; Oriyama *et al*., 2014). Heart rate frequency has also been found to decrease during sleep (Van De Borne *et al*., 1994; Su *et al*., 2008), while being sensitive to the effects of fatigue, where responses increase as a result of increasing task demands or stress (Dutheil *et al*., 2012) or decrease during conditions of under load (Jorna, 1992).

2.5.2.2.1 Heart rate variability

The usefulness of HRV measures was recognised following the discovery that it could be used as a reliable predictor of mortality following acute negative cardiac events (Kleiger *et al*., 1987; van Ravenswaaij-Arts *et al*., 1993). The measure is now widely used as a possible indicator of cardiovascular risk associated with various health issues such as myocardial infarction and diabetes (discussed in more detail in Task Force of the European Society of Cardiology, 1996; Sztajzel, 2004).

HRV refers to the sequential variation between consecutive heart beats. More specifically, it is a measure of the time variations of the inter-beat intervals (van Ravenswaaij-Arts *et al*., 1993; Karim *et al*., 2011) used to reflect the (opposing)

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[2] An overview of the different methods used to measure body temperature is outlined in Chapter 3 under the Selection of dependent variables section.

influence of the autonomic nervous system branches (Mourot et al., 2004). Furlan *et al*. (1990) described HRV as an indicator of the functional state of an individual, which is supported by its use as a gauge of mental workload (Rowe *et al*., 1998). More specifically, HRV tends to decrease with increasing cognitive workload, mental effort or task complexity (Aasman *et al*., 1987; Veltman and Gaillard, 1996; Rowe *et al.,* 1998). This is however not a consistent finding (as discussed extensively in Jorna 1992). With respect to its parameterisation, a number of methods exist, two of which warrant consideration: the time-domain and frequency domain analyses.

2.5.2.2.2 Methods of analysis

Time domain analyses focus on assessing how the inter-beat or normal to normal (NN) intervals change over time. The simplest measures in this regard are the mean NN interval or mean heart rate (Task Force of the European Society of Cardiology, 1996). Alternatively, time domain analyses of HRV can be calculated by analysing the standard deviation of the NN intervals. Measures derived from this include the standard deviation of NN intervals (SDNN), the square root of the mean squared differences of successive NN intervals (r-MSSD), the number of interval differences of successive NN intervals greater than 50 ms (PNN50), all of which provide insights into the changes in HRV (Task Force of the European Society of Cardiology, 1996).

Frequency domain or power spectral density analyses on the other hand provide insights into the nature of the fluctuations of heart rate (Karim *et al*., 2011). This is achieved by mathematically separating the inter-beat intervals from the time domain analysis into different frequencies (Task Force of the European Society of Cardiology, 1996). This provides information on each frequency components relative intensity or power in the heart’s sinus rhythm (Task Force of the European Society of Cardiology, 1996; Sztajzel, 2004), what van Amelsvoort *et al*. (2000, p256) refer to as “a crude separation between vagal and sympathetic cardiac control”. These frequency bands range from 0 to 0.5 hertz and are typically classified into four bands.

The high frequency band (HF: 0.15–0.4 Hz) is typically associated with increased vagal activity (Malliani *et al*., 1991) while the low frequency band (LF: 0.04–0.15 Hz) is believed to be a marker of sympathetic activation (Malliani *et al*., 1991). Others hold that it reflects both vagal and sympathetic activity (Akselrod *et al*., 1981). The frequency bands also include a very low (VLF: <0.003–0.04 Hz) and ultra-low frequency band (<0.003 Hz) (Sztajzel, 2004). The ratio between these two bands (LF:HF ratio) reflects the sympathovagal balance (Task Force of the European Society of Cardiology, 1996; Burr, 2007). Normalised spectral heart rate frequency measures are also commonly applied as a means of quantifying the modulation of the sympathetic and parasympathetic branches of the autonomic nervous system (Burr, 2007; Wehrens *et al*., 2012).

2.5.2.2.3 The effects of circadian rhythmicity and shift work on heart rate variability

Previous research has demonstrated circadian rhythmicity in measures of HRV, in that HRV is normally lower during the day and higher at night, denoted through increasing sympathetic activity during the day and increased parasympathetic activity at night (Furlan *et al*., 1990; Freitas *et al.,* 1997; Massin *et al*., 2000). Other researchers have reported that the changes in HRV over a day are related more to sleep, wakefulness and the level of activity than the day night cycle (Ewing *et al*., 1991; Freitas *et al*., 1997; Furlan *et al*., 2000; Ito *et al.,* 2001: Su *et al,* 2008).

There is consistent evidence that sleep deprivation is associated with increased sympathetic and decreased parasympathetic activation (Zhong *et al*., 2005). In the context of night shift work, Furlan *et al.* (2000) reported that reduced normalised Low frequency (LFnu) values were observed during the night shift, when compared to work during the day. These authors asserted that this decrease in LFnu was indicative of a reduced sympathetic modulation, which they interpreted as a possible indicator for a reduction in alertness and an increased risk of accidents (Furlan *et al.* 2000). In their study on emergency physicians, Dutheil *et al.* (2012) found that HRV was lower while on night shift, when compared to a control, rest day. The authors attributed this to the stress associated with the job, amplified by working at night and for an extended period of time. These and other researchers assert that reduced HRV is indicative of a higher sympathetic influence and increased cardiovascular risk (Dutheil *et al*., 2012; Wehrens *et al*., 2012).

In support of this, Ishii *et al*. (2004) reported an increased predominance of the sympathetic activation in shift working nurses as compared to non-shift working ones. This is in line with Holmes *et al*. (2001) who reported higher sympathetic and reduced parasympathetic activity during sleep, following a week of simulated night shifts. In sum, working at night and under conditions of sleep loss has been associated with disruptions to the sympathovagal control of the heart. More specifically, there is tendency towards increased sympathetic influences, which has been hypothesised as one possible mechanism for the development of heart disease in contexts that involve night shift work (van Amelsvoort *et al*., 2001; Wehrens *et al*., 2012).

2.5.3 Subjective measures

In addition to the neurobehavioral and physiological measures, the assessment of subjective perceptions is relatively non-invasive and easily accessible (Annett, 2002; Åkerstedt and Wright, 2009; Zhou *et al*., 2012; Åkerstedt *et al*, 2014). This is important in situations where work processes cannot be interrupted by the objective measures mentioned above. Subjective assessments are based on an individual's experience and the information to which they have access; this refers to how perceptions are influenced by previous ratings in the context of a laboratory study or previous experiences of fatigue / sleepiness outside of it (Annett, 2002). In contrast, perceptions could also be influenced by external indicators, such as the knowledge of time of day and other more personal factors. In the case of fatigue, the need to exert more effort or increased yawning could be mechanisms that impact perceptions (Annett, 2002).

2.5.3.1 Subjective sleepiness, the circadian rhythm and shift work

Subjective sleepiness[3] refers to an individual's self-perception of their hypo-activated state (Curico *et al*. 2001), which has repeatedly been shown to reflect time of day and homeostatic influences, both in laboratory (Sallinen *et al*., 1998; Wyatt *et* al., 1999; Wright *et al*., 2002; Eriksen *et al*. 2006; Lovato *et al.* 2009) and real world

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[3] As with the physiological measures, an overview of relevant subjective sleepiness measures is provided in Chapter 3.

settings (Lowden *et al.* 1998; Axelsson *et al*., 2004; Bjorvatn *et al*., 2006; Waage *et al*., 2012). Subjective sleepiness scales, such as the Karolinksa Sleepiness Scale (Åkerstedt and Gillberg, 1990) have also shown consistent differences between morning, afternoon and night shifts. More specifically, night shifts are associated with the highest perceptions of sleepiness, followed by morning and then afternoon shifts (Lowden *et al.*, 1998). Under night shift conditions, subjective sleepiness has been reduced following a number of countermeasures, including strategic naps (eg: Smith *et al*., 2007; Smith Coggins *et al*., 2006; Kubo *et* al., 2007; Lovato *et al.* 2009), caffeine (Reyner and Horne, 1997) and physical activity (Lombard, 2010)

Although considered “less accurate” than objective measures of sleepiness (Åkerstedt *et al*., 2014), Axelsson (2005) argues that the measures of subjective sleepiness are critical. He attributes this to how such measures typically complement changes in both physiological and behavioural/performance outcomes, an assertion supported by Kaida *et al*. (2006). These authors reported that changes in certain neuro-behavioural responses were significantly related to the changes in subjective sleepiness, measured using the Karolinksa Sleepiness scale (Åkerstedt and Gillberg, 1990).

This however is not consistent with the findings of Van Dongen *et al.* (2003a), who reported that subjective sleepiness did not match the rather linear performance decrements associated with 14 days of sleep restriction. Similar findings have been made during Forced desynchronization protocols (Zhou *et al.,* 2012) during which the authors stressed that the differences between objective and subjective measures was more pronounced during the biological night. Additionally, other studies (Kubo *et al*., 2010; Tremaine *et al*., 2010 and Signal *et al*., 2012) have reported that napping during simulated night shifts and the resultant effects of sleep inertia may contribute to dissociation between objective and subjective measures. More specifically this refers to how individuals may perceive to be less sleepy following a nap, but their performance does not correspond with this perception.

2.6 SUMMARY

The practise of shift work, which includes work at night, has consistently been associated with disruptions to the innate circadian rhythm and normal sleep wake cycle. These challenges, accompanied by individual and task-related factors, contribute to the development of sleepiness and fatigue, complex and individual-specific experiences that are accompanied by reductions in alertness and consequently performance. In previous research, the quantification of this performance was typically achieved through understanding its effects on various elements of the information processing chain. To gather insights into the changes in physiological arousal, the inclusion of temperature and heart rate measures is also important. These measures are further complemented by records of self-rated sleepiness or alertness. Although many different organisational, behavioural, chronobiological and pharmacological countermeasures are practised in the attempt to limit the effects of fatigue, there is still scope to explore new ways to achieve this.

CHAPTER 3: METHODS

3.1 INTRODUCTION AND RESEARCH CONCEPT

In the previous chapter, relevant literature was included to emphasise that during night shift work, workers suffer from disruptions to their circadian rhythm which may in turn negatively affect their quality and quantity of sleep. This stems mainly from the need to work against their natural inclination to be awake during the day and sleep during the night. At night, physiological arousal is reduced, which when combined with extended wakefulness and sleep loss, predisposes workers to reductions in alertness and performance (Gold *et al*., 1992; Smith *et al*., 1994; Folkard and Tucker, 2003). These compounding effects are no more apparent than when workers rotate into or have to start the first night shift (Purnell *et al.,* 2002; Santhi *et al*., 2007; Horne, 2012), which can be associated with extended wakefulness prior to the start of the shift (Folkard, 1992; Sack *et al*., 2007). These detrimental effects on alertness may be accentuated over consecutive night shifts due to reductions in recovery sleep and the development of sleep debt (Van Dongen *et al.,* 2003a; Van Dongen *et al*., 2003b; Belenky *et al.,* 2003). In essence, the start of a phase of night shifts and the remaining shifts contribute to reduced worker alertness, performance and safety.

In light of this, the review provided an overview of the extensive research that has explored different means of enhancing alertness during night shifts, while also maximising opportunities for recovery during periods of night shift work. Organisationally, although no ideal shift system exists, general ergonomic recommendations for shift scheduling may assist in the development of an "acceptable" or best compromise shift system (Folkard, 1992; Ferguson and Dawson, 2012). Some of these recommendations include rapid shift rotation (Härmä *et al*., 2006; Härmä and Hakola, 2006; Klein Hesselink *et al*., 2011), that rotate in a forward or delaying fashion (Czeisler *et al*., 1982; Knauth, 1993; van Amelsvoort *et al*., 2004), that allow an adequate recovery period between shifts and that limit the number of consecutive night shifts (Knauth, 1993; Kundi, 2003) and the risks associated with quick returns (Videaa *et al*., 2015). However, irrespective of the speed or direction of rotation, the challenges associated with transitioning into the first night shift remain. This problem was the basis upon which the concept of a gradual, rather than characteristically rapid rotation into the night shift was studied using the *Rolling rotation* condition. The aim of this particular element of the study was to determine whether a gradual introduction to the night shift would lessen the sleep, alertness and performance-related decrements typically associated with a rapid transition into night work.

A second method used to improve shift worker alertness while on shift is the implementation of napping opportunities, the effects of which have been studied in operational (Rosekind *et al*., 1994; Valk and Simons, 1998; Sallinen *et al*., 1998; Bonnefond *et* al., 2001; Purnell *et al*., 2002; Signal *et al*., 2009; Roach *et al*., 2011) and laboratory settings (Gillberg, 1984; Rogers *et al*., 1989; Takeyama *et al.,* 2002; Takeyama *et al*., 2004; Kubo *et al*., 2007; Kubo *et al*., 2010). Previous research has indicated that naps taken at night while on shift assist in reducing the extent of time awake, while supporting the biological inclination for sleep. In instances where consecutive night shifts need to be completed, cumulative sleep debt and its associated reductions in alertness and performance are likely (Van Dongen *et al.,* Belenky *et al.,* 2003a). Strategic napping can limit this to some extent. Although there are no universal recommendations around the ideal nap length and timing, the benefits of sleep are dose dependent (Bonnet, 1991), in that a longer nap usually has longer lasting effects upon awakening. However, elongated naps at night are not practical, as individuals spend extended periods away from work and the risk of sleep inertia affecting alertness post nap is also increased. In some work settings, protected sleep opportunities enable personal to obtain an extended nap opportunity while work time is covered by additional staff. This arrangement is common place in extended duty periods, but its efficacy in the context of standard eight-hour shifts remains equivocal. This formed the foundation for the conceptualisation of a split shift nap condition, which facilitated studying the effects of an extended nap opportunity between two separate four-hour work shifts.

3.2 EXPERIMENTAL DESIGN

3.2.1 Considerations around study length

This study was housed in a laboratory setting and spanned five consecutive days, of which the first was an afternoon shift and the proceeding four, were night shifts. The duration of the testing period was set at five days as most industries would rotate shifts on a weekly basis. Ideally, it would have been preferable for the testing period to be longer, but this was limited by the fact that it had to coincide with the University vacation during which the student volunteers could participate. This length of data collection was also selected as previous research (Hart *et al*., 2006) recommended a minimum of at least three night shifts in order to determine the effects of an intervention. These authors attributed this mainly to the negative effects of the initial night shift and the need to observe how responses change during subsequent shifts. Moreover, Lamond *et al*., (2003; 2004) reported circadian adaptations and concomitant improvements in performance after four standard night shifts even though the entire data collection was seven night shifts. Five consecutive shifts were also necessary to facilitate the *Rolling rotation* intervention, discussed below.

3.2.2 Independent variables

This study consisted of four experimental conditions, which were tested with four separate, independent groups during the five-day shift cycle. These were the *Rolling rotation* condition, the split shift *Nap early* condition, the split shift *Nap late* condition and the *Fixed night* condition (explained in detail below). During the data collection, participants in each condition were required to complete five, consecutive eight-hour shifts, which included one afternoon shift and four night shifts. Irrespective of the design of the condition, working time was consistent across all conditions. Between shifts, participants could return to their homes.

3.2.2.1 Rolling rotation condition

3.2.2.1.1 Background and design of this condition

As entering the night shift is challenging, this study explored the effects of gradually introducing participants into the night shift so as to avoid the rapid eight hour change typical of industrial shift arrangements and rapid time zone crossings. This was achieved through the *Rolling rotation* condition. To the knowledge of the author, this shift rotation design is novel and has not been conceived of or researched prior to this thesis. A schematic of the condition's design is shown in Figure 4.

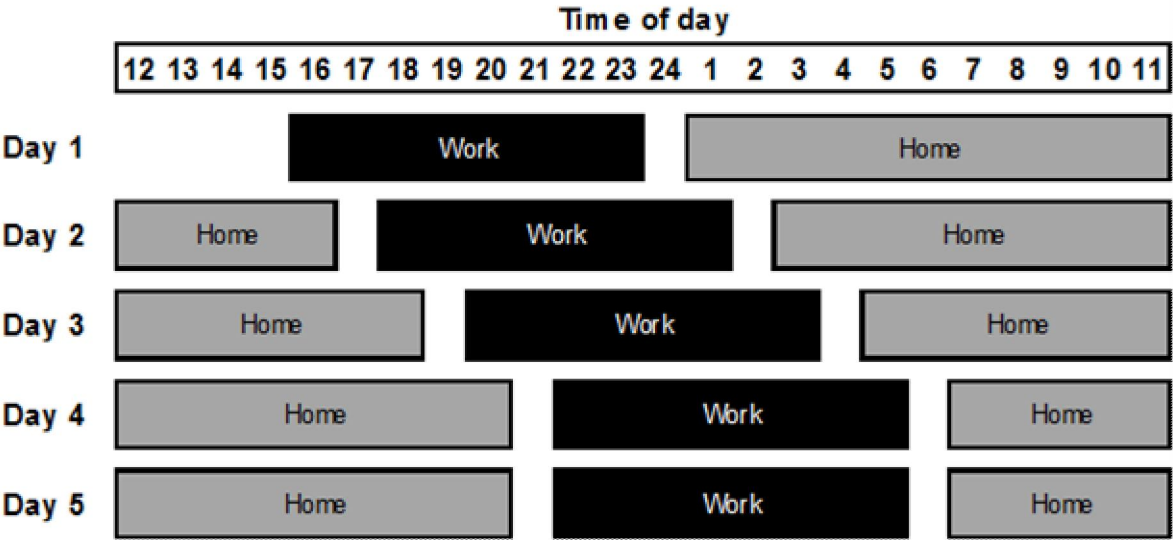

Figure 4: Schematic of the shift arrangement for the *Rolling rotation* condition.

The *Rolling rotation* condition was achieved by gradually rotating subsequent work shift start and end times by only two hours, rather than eight hours (Figure 4). The first shift began at 16h00 and finished at 00h00 (where the *Fixed night shift* and Split shift nap conditions started this shift at 14h00 and finished at 22h00). This two-hour delay was repeated over the following two shifts, until the *Rolling rotation* start and end times matched those of the *Fixed night* condition (22h00 to 06h00). Thereafter, participants in this shift system completed one more "pure" night shift to complete the five-day shift cycle. During each shift, three evenly spaced 15-minutes breaks were scheduled roughly every two hours.

The structure of the system ensured that, for three out of the four test days, the participants within the *Rolling rotation* condition had the opportunity to initiate their "recovery" or post shift sleep during some part of the habitual night time. This limited the number of consecutive night shifts and the number of hours spent working the "pure" night shift. It was hypothesized that this would increase the quantity of the group's reported sleep leading up to the first, full night shift (which would be the fourth shift) and generally over the testing period. In turn, this may have limited the degree of sleep loss (and accumulated sleep loss) experienced, resulting in fewer decrements in alertness and the sustention of night time performance, as compared to that of the *Fixed night* condition. Lastly, owing to the structure of the rotation, the amount of time off between each shift was longer (18 hours for the first three shifts, 16 hours between the fourth and fifth shift). This afforded the participants more time to obtain adequate sleep between shifts. The breaks were scheduled to occur roughly two hours apart, which Tucker (2003), following a review of relevant literature, referred to as standard scheduled rest breaks.

3.2.2.2 Split shift nap combination: Nap early and Nap late

3.2.2.2.1 Background and design of this condition

In order to facilitate an extended nap opportunity during the eight hour shifts included in the current study, two independent groups worked split shifts in a staggered manner. Split shifts refer to two distinct periods of work that are separated by a minimum of two hours. Although common in maritime watch systems, rail and medical work contexts where extended periods of duty are practiced, research around the plausibility and benefits (if any) of split shifts is limited (Wright *et al.*, 2013).

Two independent groups completed two, staggered four-hour work periods, separated by an extended nap opportunity (illustrated in Figure 5). This arrangement resembled the concept of a protected sleep period, which is practised in medical contexts (eg: Volpp *et al*., 2009; Shea *et al*., 2014). With respect to the break schedules, the allotted, total 45-minute break time was divided in to two 22.5 minute breaks during each four-hour shift. This still meant that participants in these two conditions did not work for more than two hours without having a break. The structure of this arrangement also facilitated the coverage of 16 hours of a standard working day.

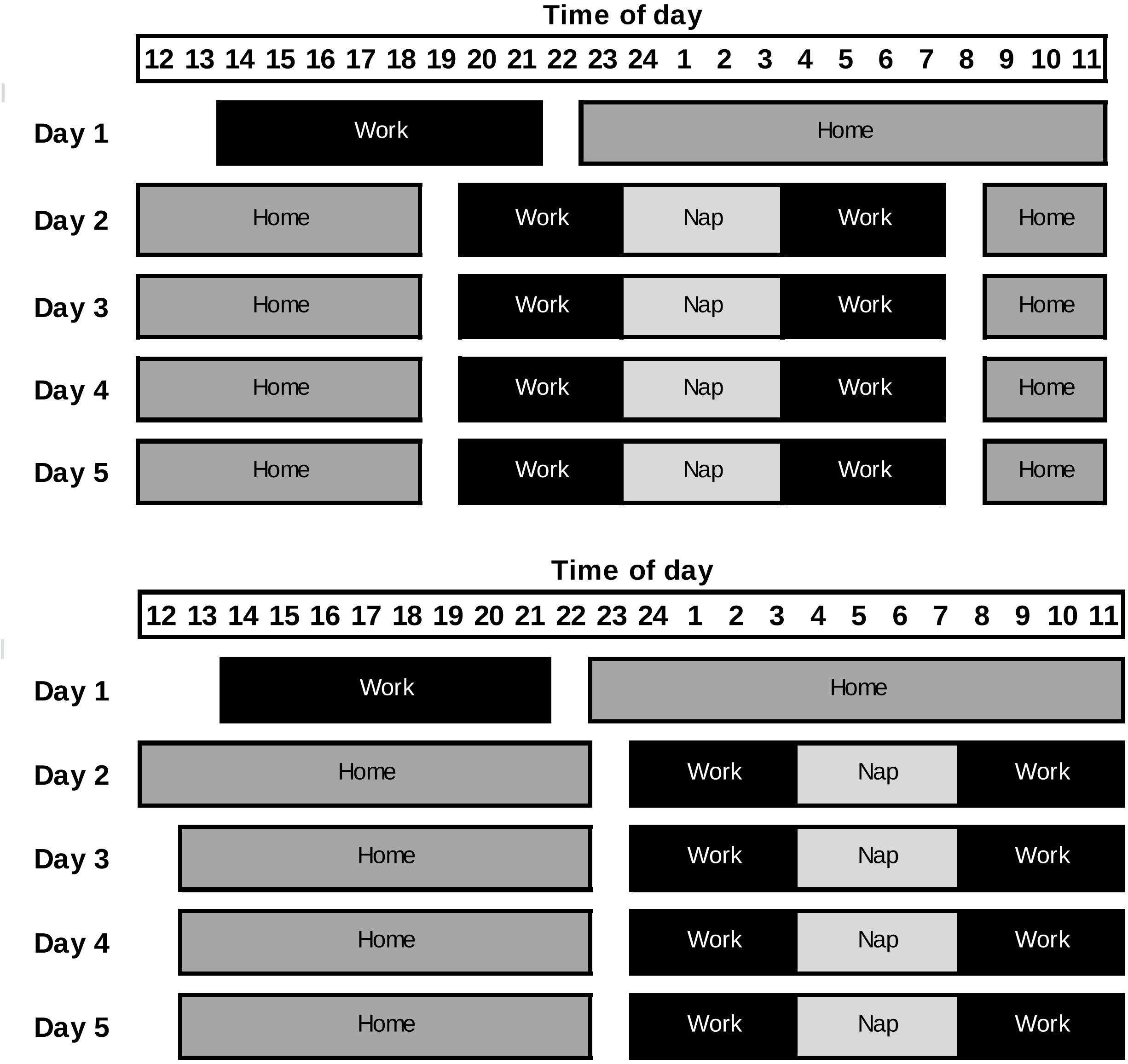

Figure 5: Schematic of the shift arrangement for the *Nap Early* condition (top panel) and the *Nap Late* condition (bottom panel).

3.2.2.2.2 Selection of sleep length

From a research perspective, napping interventions differ significantly with respect to the context in which they are applied, the length of the naps (Brooks and Lack, 2006; Takeyama *et al*., 2004; Kubo *et al*., 2007), their frequency (Oriyama *et al*., 2014) and their timing (Gillberg, 1984; Takeyama *et al*., 2002; Takeyama *et al*., 2004; Kubo *et al*., 2007; Davy and Göbel, 2013). This has and still does make universal recommendations around napping challenging. With respect to the length of the nap, the general recommendation is to avoid naps that are longer than 30 or 40 minutes, which limits the depth of sleep (slow wave sleep) obtained and the ensuing sleep inertia that may follow (Brooks and Lack, 2006). It is also held that shorter naps improve objective performance relatively soon after awakening. They are also easier to implement as their duration may coincide with the length of work breaks (Purnell *et al*., 2002). However, the time course of the benefits after shorter naps is inconsistent: although objective performance is improved, shorter naps are typically not perceived to be recuperative. Longer naps (+40 minutes up to 4 hours) have elicited improvements in post nap alertness and performance under sleep deprivation (Dinges *et al*. 1987; Dinges *et al*., 1988) and shift work conditions (Sallinen *et* al., 1998; Signal *et al*., 2009; Davy and Göbel, 2013; Shea *et al*., 2014) with these benefits responding in a dose dependent manner. This was an important consideration for this thesis.

Extended naps are also typically adopted during extended working hours to limit time awake, while also being dependent on whether or not an extended period away from work can be covered by additional staff. This has recently been explored in medical contexts, where protected sleep opportunities of between three and five hours (Volpp *et al*., 2012; Shea *et al*., 2014) were systematically investigated. However, the positive effects of longer naps may take longer to manifest, as the presence of sleep inertia following deeper sleep is more likely (Lovato and Lack, 2010). Although napping is reported to improve alertness and performance, while decreasing sleepiness during sleep deprivation and extended shifts, little research has explored the effects of extended nap opportunities (+120minutes) in an eight-hour shift setting. Therefore, a longer nap, if applied at the correct time (with respect to circadian phase) during night shift, may have a more prolonged effect than a shorter one, provided the sleep inertia is managed appropriately. As such, a nap opportunity of three hours and 20 minutes was selected.

This length was chosen mainly for logistical reasons. The length of the break period between the two, four-hour work period was four hours. A nap opportunity of three hours and 20 minutes allowed for a relatively extended opportunity to obtain sleep while also facilitating a period of 20 minutes for the participants to gather themselves after waking, and a further 20 minutes to complete a post nap test battery. The benefits of sleep (upon awakening) are dose dependent and this extended nap was hypothesised to improve alertness during the second part of the shift (Lovato and Lack, 2010; Mulrine *et al*., 2012). The differences between the two conditions were merely the timing of each work and sleep period, described below.

3.2.2.2.3 Selection of nap timing:

Nap early condition

Participants in this condition were required to complete one standard afternoon shift (14h00 to 22h00) and four consecutive night shifts (Figure 5, top panel). These began at 20h20. At 00h00, this group completed a *pre* nap test battery (considered to be work time as it fell during the initial four-hour work period), after which the nap began at 00h20 and ended at 03h40. Following the nap opportunity, 20 minutes was set aside for the participants to gather themselves, a period referred to as a buffer zone. Although the extent of sleep inertia is dependent upon a variety of factors (discussed in the Sleep inertia section, p38 in Chapter 2), previous research has recommended a period of at least 15 minutes (Tassi *et al*., 1992), while other findings suggested 30 minutes (Ferrara *et* al., 2000) prior to returning to work. Other researchers have reported the presence of sleep inertia hours after awakening (Jewett *et al*., 1999). However, differences in nap length and their timing make recommendations around a buffer period difficult. Due to limited time frame between the nap ending and start of the post nap test battery, 20 minutes had to be selected. Thereafter the post nap test battery was completed (which was not considered to be work time, as it occurred during the four hour break period).

The timing of this particular nap opportunity period were based on the observations by Lavie (1986), who reported that between 21h00 and 04h00, there is a dramatic increase in sleep propensity, which favours the onset of sleep. Furthermore, owing to the nap occurring prior to the build-up of sleep pressure (that is, the resultant sleep pressure that results from extended wakefulness), the extent of the sleep inertia may not be as pronounced as compared to a nap scheduled later than this (Balkin and Baida, 1988; Hofer-Tingeuly *et al.,* 2005) despite the point of wakefulness being near to the nadir. Upon completion of the post nap test, work continued from 04h20 and ended at 08h20.

Nap late condition

In order to “cover” the *Nap early* group during their nap opportunity, the *Nap late* condition was necessary. Following the initial afternoon shift, the *Nap late* condition also completed four night shifts, during which the eight-hour work period was split into two shorter four-hour work periods. The first four hour work period was scheduled between 00h00 and 04h00 (pre shift test; 23h40), which coincided with the start of the sleep period of the *Nap early* condition (Figure 5, bottom panel). At 03h40, a pre nap test battery was completed and the *Nap late* condition retired for their sleep period which coincided with the start of the second four hour shift for the *Nap early* condition.

The nap for this group was scheduled to start at 04h00 for two reasons; firstly, the homeostatic and circadian pressure for sleep would be high, owing the expected extended wakefulness experienced by this group. Secondly, as reported by Matsumoto (1981), Gillberg (1984) and Kubo *et al*. (2007), extended naps scheduled near to the nadir were more effective (than earlier ones) in lessening the accumulated sleepiness from being awake during the subjective night. Between 04h00 and 08h00, the work task was assumed by the *Nap early* condition. At 07h20, the *Nap late* condition participants were woken and following the 20minute “wake up” period, completed a post nap test battery at 07h40 before returning to work for the last work period between 08h00 and 12h00.

Again, the timings for this condition were such that, after the *post* shift test, this group returned home and could take advantage of the “postprandial” sleepiness and the increased sleep propensity that has been observed during the early afternoon (Lack and Lushington, 1996). This assumption is further supported by Lavie (1986), who found that sleep obtained during the “afternoon dip” (15h00 to 17h00) was better than that obtained between 19h00 and 21h00. Following the completion of the second, four hour shift in both nap conditions, participants had a total of 12 hours to recover before the start of the next shift, affording ample opportunity for recovery sleep.

In sum, the design of these two nap conditions favoured “sharing” the difficulties inherent in working the night shift and afforded the opportunity for both groups to obtain sleep during the habitual night time. Lastly, no “production” time was lost as the total work time was the same as the other two conditions.

3.2.2.2.4 Napping environment

The designated sleeping areas were removed from both the working and testing venues. The dormitory rooms were dark and quiet, with black plastic being used on the windows and doors to prevent any natural or artificial light from entering the rooms.

3.2.2.3 Fixed Night shift condition

This condition (illustrated in Figure 6) was representative of a standard system found in industries that implement weekly rotating shift systems that are longer than what is considered rapid rotation (every 1 to 3 days; Williamson and Sanderson, 1986; Wilkinson, 1992). This condition served as a reference condition to the other three intervention groups. Participants allocated to this shift arrangement were required to complete one afternoon shift (≈14h00 to 22h00), followed by four consecutive night shifts, scheduled between 22h00 and 06h00. Similar night shift arrangements and timings have been reported (Åkerstedt, 1998) and adopted in previous simulated night shift studies (Lamond *et al*., 2004; Kubo *et al*., 2007; Kubo *et al*., 2010; Lombard, 2010; Davy and Göbel, 2013).

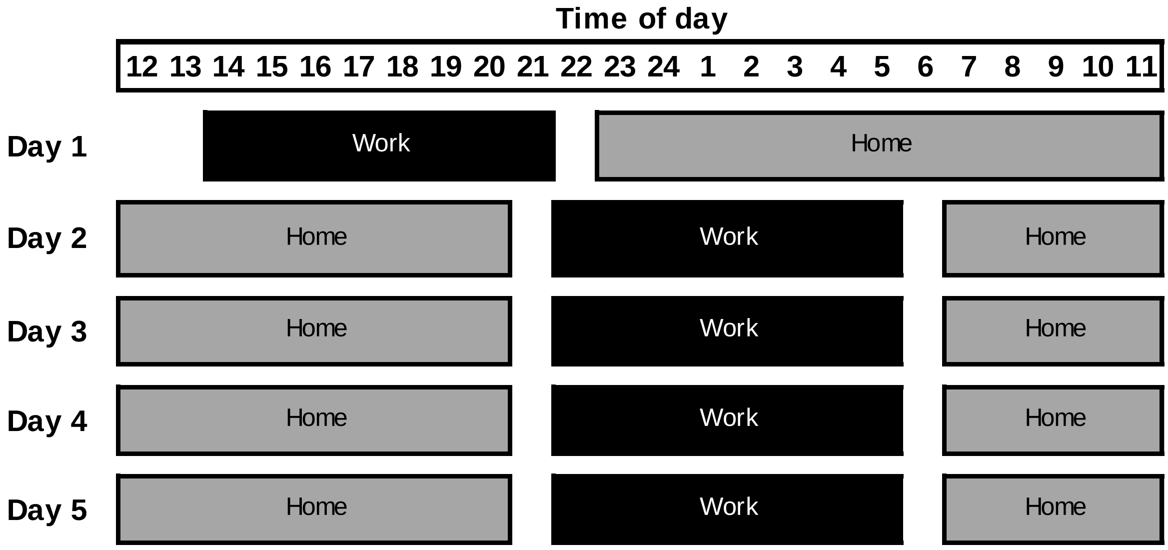

Figure 6: Schematic of the shift arrangement for the *Fixed night shift* condition.

This particular condition required rapid adjustment to an eight hour shift in their sleep-wake cycle when rotating from the afternoon to night shift, similar to a forward rotating standard shift regime. Three evenly spaced 15-minutes breaks were scheduled per shift which were interspersed by six test batteries (to be discussed below).

3.2.2.4 Selection of work task

Task requirements play a major role in the degree of fatigue and sleepiness experienced by workers, particularly during a night shift. Monotonous work tasks such as elongated vigilance or inspection tasks can lead to boredom, the effects of which are similar to, and difficult to differentiate from fatigue and the associated reductions in performance proficiency and task engagement (Desmond and Hancock, 2001). In contrast, cognitively taxing work can result in overload and attentional narrowing, the effects of which also compromise performance (Desmond and Hancock, 2001). Similarly, self-paced tasks tend to be more indicative of an individual’s alertness levels when compared to externally paced ones (Blatter and Cajochen, 2007). In order to ensure that participants were not overly taxed cognitively or completely bored, a very simple, repetitive bead threading task was selected.

This beading task was used in previous research by the author (Davy and Göbel, 2013) and was included as a monotonous and repetitive means of keeping the participants occupied during each shift. Furthermore, beading performance (mass of beads used per work period) was also found to reflect the effects of extended wakefulness and time of day, in that “performance”, measured through beading output significantly decreased over each night shift (Davy and Göbel, 2013).

3.2.2.4.1 Requirements of the beading task

Each participant was presented with a 1m piece of beading gut or beading (nylon) elastic, an 8 cm piece of aculon or “tiger tail” which fulfilled the role of a beading needle, and six types of different coloured, medium-sized, glass beads (8/0 = 12 beads per inch). Although specified designs were provided, participants were free to combine different designs together or create their own. The only restriction was the method by which the participants had to thread the beads onto the gut or elastic; participants were required to thread the beads on carefully from their hands or the table (Figure 7). Completed pieces were placed in front of each participant and during each test battery, the mass (grams) of all completed and uncompleted work was recorded and used as a performance/productivity indicator.

Figure 7: The beading task

3.2.2.5 Laboratory conditions

All experimentation occurred in a laboratory setting, which was quiet and removed from any major roads or sources of everyday noise. The light levels within the work place were kept relatively constant during both the afternoon and night shifts; artificial fluorescent lighting maintained a luminance of between 400 – 500 lux at the level of each participant's eye. The temperature in both the working and testing areas was kept relatively constant (between 20 and 23^{o}C) and toilet facilities and fresh drinking water was available throughout testing.

3.2.3 Selection of dependent variables and relevant equipment

The current research project adopted a holistic approach to assess the effects of the different conditions on the development of fatigue during the series of night shifts. The dependent variables were selected to provide insight into the effects of night work and the inherent circadian and sleep-related changes that accompany this type of work. Selected performance, perceptual, cognitive, psychomotor and physiological measures and crude sleep indicators were included and are explained in detail below.

3.2.3.1 Performance measures

3.2.3.1.1 Beading performance

In an attempt to simulate a monotonous and repetitive assembly task, participants were required to complete the simple beading task previously explained. Beading output was determined by weighing the beads that had been threaded onto beading gut or elastic, using an electronic digital platform scale (@HOME) that had a threshold sensitivity of 1g. Thereafter, beading performance was calculated as beads produced per work period (that is, between the respective tests). More specifically, this referred to the total bead produced between test 1 and test 2, test 2 and test 3, test 3 and test 4 and test 4 and the post test. This meant that there were four distinct work periods during which beading output was analysed.

3.2.3.2 Information processing / Cognitive performance tests

Cognitive performance is multifaceted and involves the complex interaction of information processing and motor output. As such, it is difficult to test all elements involved in cognitive performance in one test. In light of this, the cognitive tests selected as dependent variables in this study included a variety of cognitive resource-specific tests, designed to isolate (as far as is possible), perceptual, cognitive and psychomotor resources that form part of the information processing chain (Wickens, 1984). While all tests of this nature require most cognitive processes during their completion, each selected test focused on one predominating element of the information processing chain. Although the human information processing model is a relatively simplified, it is a clear and distinguishable model, upon which the tests that were included in the current thesis were designed (prior to the current study). Thus, the model serves as a crucial theoretical underpinning due to its inclusion in the conceptual development of the test battery. Furthermore, although the model is relatively old, it is still very relevant and is still used in very recent sports science and cognitive ergonomics research. More recent models would also be derivatives of the human information processing model. The test battery included in this study was the same as that which was applied in previous research in the author’s department (Goble, 2013; Huysamen, 2014).

Each performance test included in this study was also comprised of two levels of difficulty. These were either tested together in one test scenario or as two separate tests performed. Previous research has emphasised that simpler versions of the same task are more sensitive to the effects of sleep loss, time of day and fatigue (Bonnefond *et al*., 2003), while others found this with the more difficult versions (Blatter *et al*., 2005). While the outcomes would depend on the nature of the modality or stage of information processing being tested, this disparity warranted the inclusion of two levels of difficulty. Ultimately, their inclusion facilitated insights into the effects of the night shift conditions on different parts of the human information processing chain and the potential effects of the different experimental conditions.

3.2.3.2.1 Validity of the tests

The tests outlined in the following paragraphs have been applied in previous research in author's laboratory. This has included the effect of alcohol (the effects of which have been repeatedly found to "mirror" the effects of fatigue due to sleep loss and time of day) and caffeine (Goble, 2013), monotony and time on task (Ngcamu, personal communication). Furthermore, although they are all "new" tests in the sense that they were built in-house, they were designed around existing, similar tests. While this doesn't resolve the issue of validity, their inclusion in this study formed part of the novelty element.

3.2.3.3 Visual perception tests

To test the effects of night shift work and the different experimental conditions, four visual perception tests were included in the current test set up. Such tasks, which include, *inter alia* simple and choice reaction time, visual search, vigilance and basic tests of attention, have previously reflected the effects of time of day (eg: Lamond *et al*., 2004; Valdez *et al*., 2005), extended wakefulness (Lamond and Dawson, 1999; de Gennaro *et* al., 2001; Santhi *et al*., 2007) and night shift work more generally (Ferguson *et al.* 2012a).

In light of this, a number of visual perception tests were included in the test battery to gain insights into the effects of the simulated night shift conditions on the participant's ability to receive, process and perceive information. They included an eye accommodation test, a visual detection test, a visual object recognition test (in the form of a reading task) and a simple reaction time test.

3.2.3.3.1 Accommodation test

The accommodation test was included to test the perceptual aspects of the information processing system. For the purpose of this study, the accommodation task was adapted to measure and compare the effects of changing convergence and accommodation on the perceptual system during the different night shift system conditions. In addition to this, the test contained a simple decision making component in the form of a two-choice reaction time task. This test was based on the same one used by Goble (2013) and Huysamen (2014), who included the test to measure the effects of alcohol and work shift fatigue on dynamic accommodation time respectively.

Test design, instrumentation and outcome measures

Participants were seated during the test, and positioned 40cm from a small laptop screen in front of them. Directly behind this screen, 150cm away from the participant was a second screen, onto which the same image that was on the laptop was projected. One half of each screen was covered (Figure 8). This was done so that when the participant was positioned correctly, the two halves of each screen effectively made one screen. The stimulus, a white square on a black background randomly alternated its appearance between the close and far screens. Contained within each white square was a small black dot, which appeared on the left or the right side of the square. To successfully complete the test, the participants were required to click the left or right mouse buttons as rapidly as possible in response to the side on which the small black dot appeared in the white square. This aspect introduced a low-order cognitive aspect (decision making) to the task. Essentially, there were two levels of difficulty to this task that were combined during one testing scenario: the static level, where the abovementioned stimuli appeared repeatedly on the near screen (near vs near) or the far screen (far vs far). The other level was dynamic in nature, during which the stimuli changed between the near and far screens. The test was 120 seconds in duration.

Accommodation time was used as a performance indicator and was determined by building a difference between the static level of difficulty (near vs near and far vs far) and the dynamic level (near vs far). Choice reaction time was calculated by considering the median reaction times in response to the changing position of the black dot in the white square, irrespective of whether it appeared close to or far from the participant. Where appropriate, median values from the cognitive test were selected as they are more robust than mean values due to the fact that outliers are eliminated.

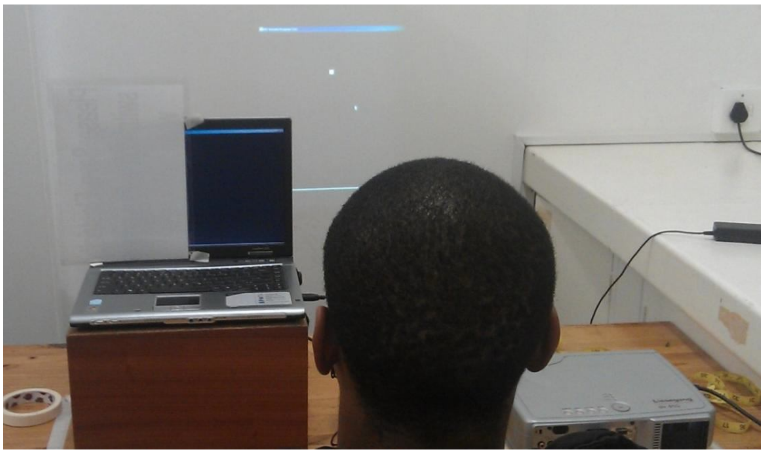

Figure 8: The Accommodation test setup.

3.2.3.3.2 Visual detection test

The visual detection test (VDT) was included as an indicator of selective attention towards the recognition of a critical stimulus amongst a host of distractor stimuli. This measure has previously been sensitive to the effects of alcohol (Goble, 2013), the effects of which have been likened to those of fatigue associated with extended wakefulness (Dawson and Reid, 1997; Lamond and Dawson, 1999).

Test design, instrumentation and outcome measures

This computer-based test required participants to identify and respond to a critical stimulus (a red dot) which appeared randomly amongst a number of irrelevant stimuli or distractors (white dots) that were moving in random directions from one another. The size of all stimuli were set at 2mm x 2mm and shaped in the form of circles (Figure 9). Each participant was required to respond to the critical stimulus by clicking a computer mouse as soon as it was observed.

The critical stimulus would appear in varying spatial orientations (from various parts of the screen) on the screen at random intervals between 300 and 1000ms. Furthermore, two levels of difficulty were tested separately; during the more difficult version, the critical stimulus appeared amongst 80 distractors, whereas the simpler test was comprised of 40 distractors. Each test took 60 seconds to complete, and participants were requested to remain a standardised 50 cm away from the screen to ensure viewing distance was not a confounding variable. This test was performed on a 23” HP T230i Wide LCD monitor; this large screen was selected so that both peripheral and centralised aspects of vision could be tested. Performance was indicated by the median reaction time to the stimuli that were detected. Additionally, the percentage of the stimuli overlooked (also referred to as error rate) was included as an outcome measure.

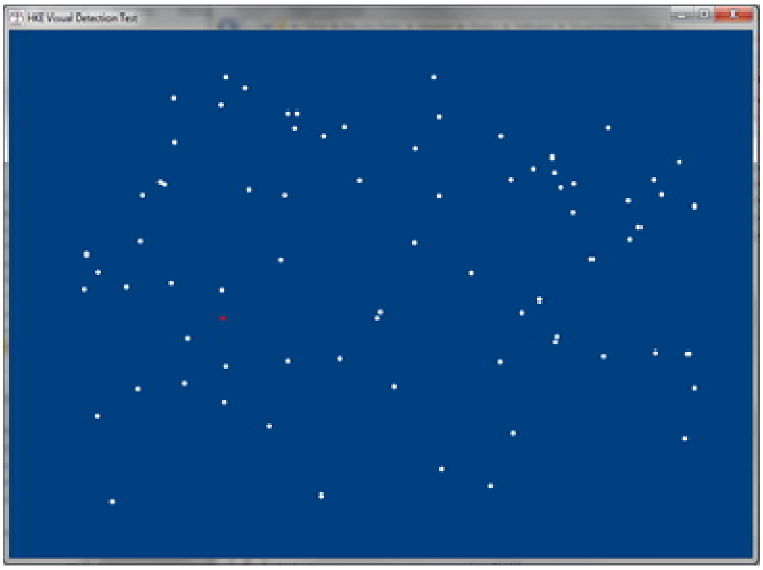

Figure 9: A screen shot of the Visual detection test with 40 distractors.

3.2.3.3.3 Visual object recognition (reading) test

A visually demanding reading test that was adapted from Chaplin (2010) (in that the test in the current study was significantly shortened) and Goble (2013) was included in the test battery. In previous research, the outcome measures of this task reflected the fatiguing effects of the night shift in *real world* shift work settings, in that processing (reading) speed decreased (Huysamen, 2014). In contrast, Goble (2013) reported that reading speed was unaffected by alcohol consumption, did not differ between sex and was insensitive to time of day (morning: 10h00) and evening: 22h00).

Test design, instrumentation and outcome measures

Participants were required to read and carefully scan a hard copy text for errors in the form of double letters (for example; bookk). On average, there were 5 errors per 100 words. This constituted the object recognition element of the task. The actual reading material used was sourced from various news stories obtained off news websites, written in English. These texts were easy to read and understand. These documents were then saved and printed at two levels of resolution using the same printer: 300dpi (high resolution) and 60dpi (low resolution). The format (but not the content) of the text was constant between both resolutions; 12ppt Times New Roman font was chosen and the texts were justified columns with 1.15 line spacing.

The two resolutions represented two levels of difficulty. The simple version (Figure 10, left), which was less visually demanding, involved reading and scanning text for errors at a 300dpi resolution (a normal reading text resolution). The more difficult version (60dpi resolution) was more visually demanding and made object recognition (text errors) more challenging (Figure 10, right). Participants read each text for 90 seconds. Identified errors were circled using a pencil and the amount of text read in the allotted time was marked. The inclusion of this test facilitated insights into the effects of night shift work on the outcome measures of processing speed (as indicated by reading speed: words read per minute) and pattern recognition (as indicated by the percentage of errors identified, also referred to as reliability).

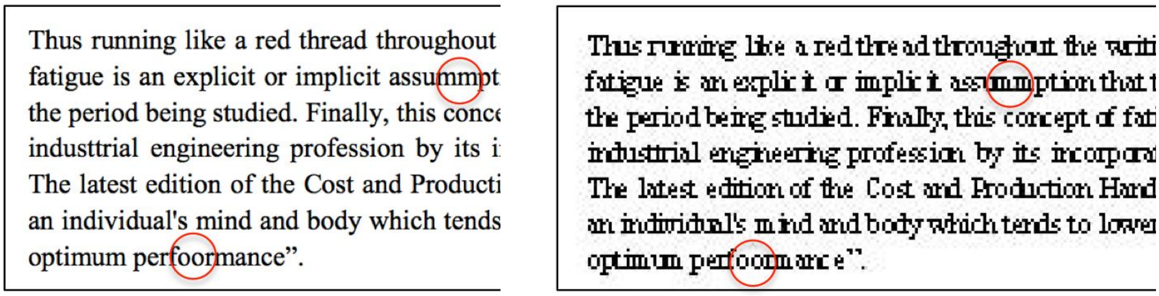

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Figure 10: Extracts of the high resolution (left) and low resolution (right) texts used during the object recognition test.

3.2.3.3.4 Simple reaction time test

The inclusion of a simple reaction time measure provides fundamental insights into the arousal level of an individual and is typically assessed through similar measures such as the Psychomotor vigilance task (PVT; Dinges and Powell, 1985). Extensive research has found that reaction time measures, a basic indicator of tonic alertness are sensitive to the effects of sleep loss and circadian disruption (time of day effects), conditions that result from working at night (Gillberg, 1984; Purnell *et al*., 2002; Bjorvatn *et al*., 2006; Smith *et al*., 2009; Hansen *et al*., 2010).

Test design, instrumentation and outcome measures

Participants performed a short simple reaction time test. A green, circular stimulus (50mm in diameter) appeared randomly in the centre of the screen (on a Hewlett Packard (HP) 23" LCD screen), with presentation time varying between 1000ms and 2000ms (Figure 11). Using a computer mouse, participants were instructed to respond as rapidly as possible to the presentation of each stimulus during this test that took 20 seconds to complete in total. In the analysis, the first trial was ignored so as not to confound the results if a particularly lengthy reaction time was recorded. Median reaction time was used as the performance indicator.

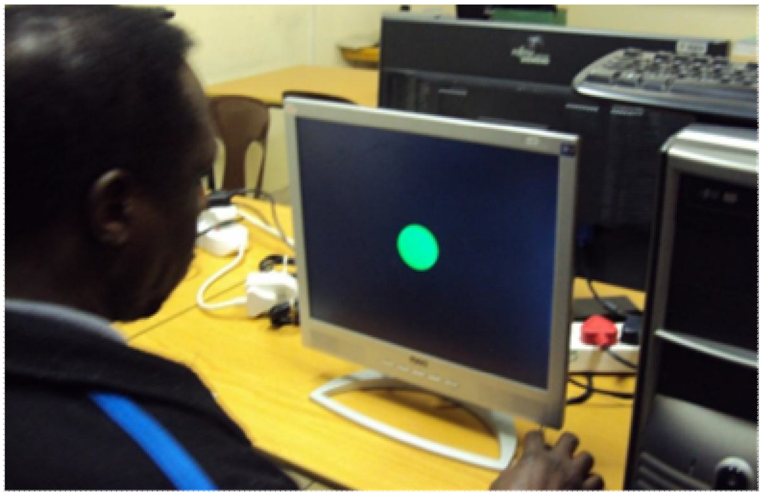

Figure 11: Participant performing the simple reaction time test.

3.2.3.4 Cognitive tests

An important element in the stage of the information processing chain is working memory (Conway *et al.,* 2005). Like the visual perceptual measures, working and other types of memory have previously demonstrated sensitivity to the circadian rhythm (Folkard, 1975; Johnson *et al*., 1992), while being negatively affected by conditions of extended wakefulness and sleep deprivation (Polzella, 1975; Maury and Queinnec, 1993; Wyatt *et al*., 1999; Smith-Coggins *et al*., 2006). In the context of night shift work, the inability to remember and recall important information may negatively affect the decision making process, resulting in either an inappropriate response or no response at all. As such, the inclusion of a working memory task was warranted.

3.2.3.4.1 Working memory (digit recall) test

This study included an adapted version of the digit recall memory task (Digit Span version 0.11) to test for attention and short term memory. The test was obtained from the PEBL Psychological Test Battery Version 0.5 (http://pebl.sourceforge.net/battery.html). The software included the program launcher as well as the necessary PEBL setup files that were modified for the purposes of this study. The original test begins with a sequence of four numbers which participants are required to correctly input. Each time a participant got the number string correct, the sequence would increase by one more number (Mueller, 2007). In instances where the sequence was incorrect, it would decrease by one number. It was from this set up that the current test was adapted.

Test design, instrumentation and outcome measures

The current test was also computer-based but differed from the original in that participants were required to memorize the sequence of a string of seven numbers that were presented visually. Following a short delay after the presentation of the last number, each participant had to remember and input the sequence of numbers originally presented by keying them in using a keypad on the computer. Throughout this test, the number string length was kept constant at seven numbers (Figure 12). The test included two levels of difficulty; the easier level involved a short delay between the stimulus presentation ending and the opportunity to start to recall which in this case, was two seconds. The more difficult level imposed a four-second delay. Test durations of 60 seconds and 90 seconds were employed for two levels of difficulty respectively. Each participant was seated in front of a computer at an arm's length away from the screen (17inch screen). The PEBL software recorded all relevant data including both correct and incorrect sequences. This information was translated into a Microsoft Excel spread sheet for data analysis. The performance outcome measure from this test was the average percentage of correctly recalled numbers (7 = 100%).

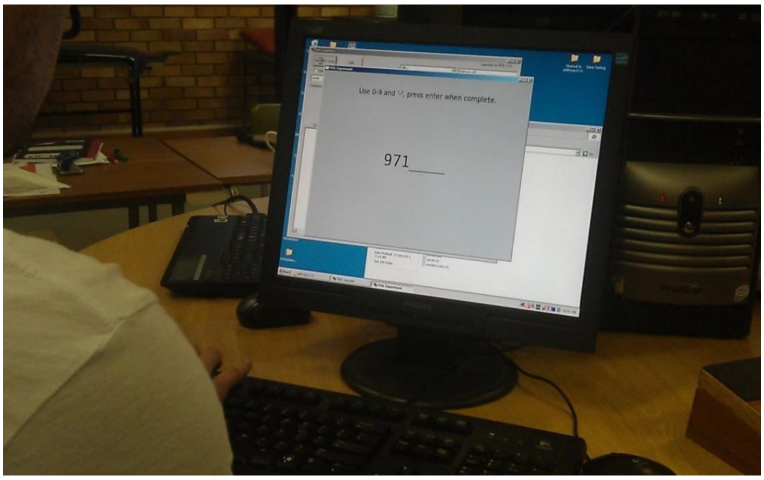

Figure 12: Participant performing the working memory test.

3.2.3.5 *Psychomotor measures*

Once information has been successfully perceived, recognised and elicited a decision pertaining to an appropriate response, a response is initiated (Wickens, 1984). Although it is difficult to isolate the effects of time of day, sleep loss or the interaction of these two factors on psychomotor responses specifically, under conditions of sleep loss, the ability to remain attentive is significantly reduced (Williamson *et al*., 2011). Furthermore, there is evidence that motor response time and control are negatively affected by conditions that evoke sleep loss and circadian disruption (Davy and Göbel, 2013). Such processes are essential in tasks such as driving. The negative effects of sleep loss and time of day on general tracking tasks have also been reported previously (Bohnen and Gaillard, 1994; Lamond and Dawson, 1999; Åkerstedt *et al*., 2005; Phillip *et al*., 2005) which warranted the inclusion of a tapping test and a continuous tracking test in the current investigation.

3.2.3.5.1 Tapping test

A tapping task applied previously by Huysamen (2014) and Davy and Göbel (2013) based on the Fitts task (Fitts, 1954), isolated the effects of the imposed conditions on motor programming time and motor response time.

Test design, instrumentation and outcome measures

The tapping test assessed the effects of night shift conditions on motor programming by assessing responses to both predictable and non-predictable target locations. This was achieved by the inclusion of both simple and complex levels, but in this instance, these levels of difficulty were amalgamated into one testing scenario. The stimulus either appeared in the centre of the screen (constituting the easier level) or anywhere on the screen (the more difficult level). Participants were required to respond to these stimuli (green dots on a black screen), by touching the stimulus on a Hewlett Packard (HP) 23" LCD touch screen in the shortest time possible using only their index finger on the dominant hand. Targets would appear one at a time on a screen with a dimension of 550x290mm. In addition to the change in location, targets also changed in size: they were either large or small, which represented low and high precision demands respectively (Figure 13).

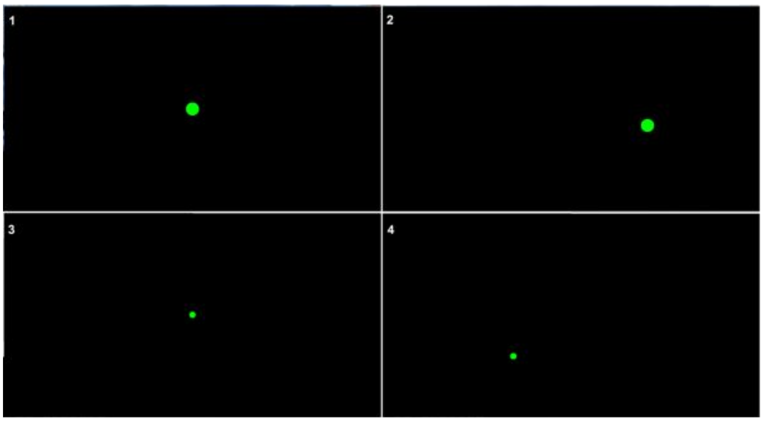

Figure 13: Stimulus response task set up (Adapted from Goble, 2013). Panel 1 = Central-large, panel 2 = Anywhere-large, panel 3 = Central-small, panel 4 = Anywhere-small.

The order of stimuli was alternated so that every second stimulus would appear at the centre of the screen. The duration of this test was set to 90 seconds, with a new stimulus appearing once the previous stimulus had been touched. Participants were seated during the test at a set distance of 50cm from the touch screen (Figure 14). Furthermore, participants were instructed to respond to the stimulus and to keep the hand in the same area of the screen once the stimulus had been responded to. This was done to ensure response time and motor programming time was not adversely affected.

All variables under study were recorded by the test software and were transferred to a Microsoft Excel spread sheet for data analysis. Performance outcomes included the time taken to respond to the stimulus from the centre to anywhere, which was defined as the time taken to program and elicit a motor response, referred to as motor programming time in this study. The other outcome measures were the response times for the high precision (small) and low precision (large) targets that appeared at different positions on the screen.

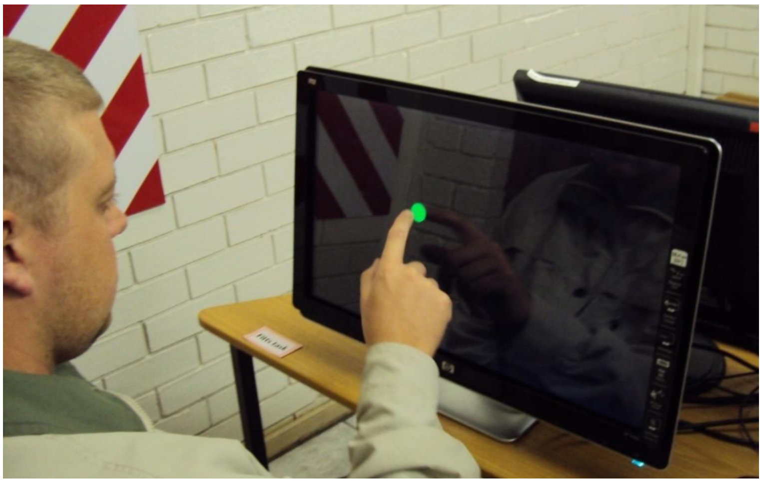

Figure 14: Participant performing the Tapping test.

3.2.3.5.2 Continuous tracking test: driving simulator test

This test, used in previous research (Goble 2013) required participants to remain attentive towards, and adjust to, deviations in a simulated driving scenario.

Test design, instrumentation and outcome measures

A low fidelity driving simulator was used for this test and involved participants performing a basic, continuous line tracking test. Participants were required to use a two dimensional driving simulator to track a white line in the centre of the constructed road (Figure 15). The driving speed was set at a constant 5 km/h, while the street width (0.68 m) and curve radius (20 – 90 m) were all kept constant. As with the other tests, two levels of difficulty subdivided the overall test into two separate tests; in this case, steering sensitivity was the manipulated variable and as a result, a high sensitivity and a low sensitivity test were performed.

Viewing distance of the simulator was 60 cm, with the simulator being displayed on a 19-inch LCD monitor. The steering wheel was a gaming wheel, while the actual computer program was constructed in the Department of Human Kinetics and Ergonomics. Participants only received visual feedback from the system with which to make adjustments to their tracking performance, which in this case, required them to keep as close to the middle line as possible. In instances where the “car” went off the road, a return button (F4) was hit to ensure that the participants returned to the road. Performance was measured through median reaction time, which produced the effective reaction delay (in seconds). This took into account the actual deviation from target line, as well as the amplitude and frequency of the deviation from this line. These factors were then used to create the reaction time related to the deviation from the target line. This parameter was therefore independent of the driving speed and the curvature of the line.

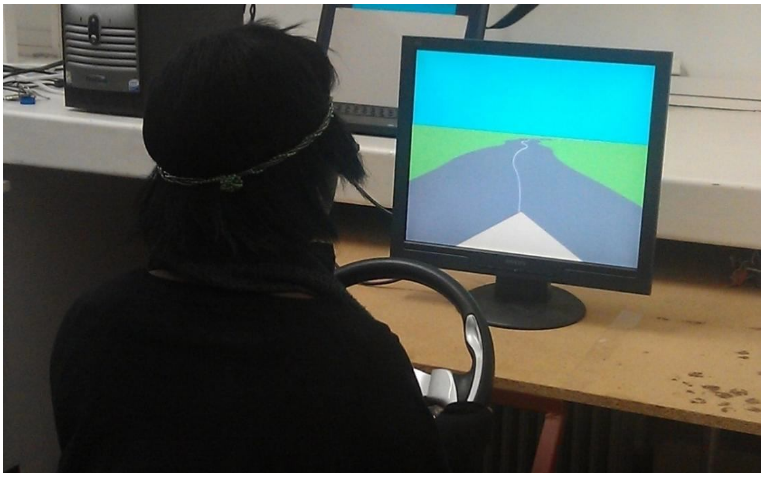

Figure 15: A participant performing the continuous tracking test.

3.2.3.6 Physiological measures

A number of physiological processes, including measures of body temperature (Wright *et al*., 2002), heart rate and heart rate variability (Furlan *et al.,* 1990; Massin *et al.,* 2000) are sensitive to changes associated with the circadian rhythm. It is also well accepted that there is a relationship between changes in certain physiological measures, such as body temperature and performance in various cognitive and neurobehavioural tests (Wright *et al*., 2002; Valdez *et al*., 2005). As such, the inclusion of a temperature measure and selected heart rate and heart rate variability measures was important.

3.2.3.6.1 Tympanic temperature

Body temperature can be measured sublingually (under the tongue: eg Smith, 1979; Knauth *et al*., 1981), under the arm (axillary: eg: Edwards *et al*., 2002), in the ear (tympanic: eg: Van den Heuvel *et al*., 1998) or rectally (Van den Heuvel *et al*., 1998; Edwards *et al*., 2002; Zhou *et al*., 2010). Although rectal temperature is the mostly commonly applied and accurate measure of core temperature, the other methods do provide some insights into circadian-related changes in temperature. Tympanic temperature, which is less accurate but also less invasive than rectal temperature measurement, is determined using an Infrared Emission Detection thermometer (IRED) (Chamberlin *et al*., 1995). More specifically, this device measures the infrared radiation that emanates from the tympanic membrane in the ear. Although the continuous measurement of core temperature would be preferable to intermittent measures (eg: Monk *et al*., 1997; Wright *et al*., 2002; Zhou *et al*., 2010), previous research (Westensen *et al*., 2002; Davy and Göbel, 2013) demonstrated a time of day effect using regular, but not continuous tympanic temperature measures. More specifically, that temperature measures decreased significantly during simulated night shifts. However, Westensen *et al*. (2002) noted that the measure is merely an estimation of the circadian rhythmicity.

Instrumentation

Tympanic temperature was measured prior to the start of each test battery to periodically track the circadian-modulated changes in body temperature over time and to determine any effects that the imposed shift conditions had on the circadian rhythmicity of body temperature. Using the Braun Thermoscan ExacTemp ® Infrared detection thermometer, which was set in “equals” mode so as to measure without adding any offset, the device recorded a total of eight measurements per second and displayed the highest temperature measured in degrees centigrade.

3.2.3.6.2 Heart rate and heart rate variability

The inclusion of these measures provided a non-invasive insight into the effects of night shift work and sleep loss on the autonomic nervous system. Previous research which has determined that changes in both HR and HRV measures under night shift (Furlan *et al*., 2000; Su *et al*., 2008; Ishii *et al*., 2005; Wehrens *et al*., 2012) or sleep deprivation (Chua *et al*., 2012) conditions may be indicative of fatigue, sleepiness and reductions in alertness and performance. Furthermore, others report that measures of HR and HRV were sensitive to different complexities of cognitive tasks (Huysamen *et al*., 2013), the effects of nap interventions during simulated (Takeyama *et al*., 2002; Davy and Göbel, 2013) and real world night shift conditions (Oriyama *et al*., 2014).

Measures selected and instrumentation

Heart rate and heart rate variability were measured continuously during each shift, during the test batteries and the work task, apart from when *Nap early* and *Nap late* participants were napping. All raw data were captured using the Suunto® memory belt system, which was uploaded to the Suunto Training manager software after each shift. With respect to time-domain measures, calculations are based on the standard deviation of the R-R intervals (the inter-beat intervals). Increasing time-domain measures are associated with a decrease in workload, performance and the increased presence of fatigue or sleepiness (Karim *et al*., 2011). Relevant measures include, *inter alia,* the SDNN, PNN30, PNN50 and r-MSSD. In this case, only r-MSSD (the root mean square of the squared difference between successive NN intervals) was included, as it provides a general perspective of the change in heart rate variability. Additionally, for the purposes of this study, only normalised values of the Low frequency power band were analysed. Normalised values were calculated using this equation (LF power / (LF+HF) as recommended by Burr (2007). This measure was included to provide insights into the predominance of either low or high power frequency responses over the course of each shift. An increase in LFnu has been associated with increasing sympathetic activation, while a decrease has been interpreted as being indicative of increased parasympathetic influence (as indicated in Burr, 2007; Furlan *et al.,* 2000; Wehrens *et al.,* 2012).

Analysis of heart rate measures

Following each shift, data from the Suunto memory belt was downloaded via a docking station, which connected to a laptop. All suunto files (sdf) were then downloaded into the Suunto training manager software (version 2.2.0). The relevant sdf files were then exported into the Data reduction and Analysis tool software, developed in the Department of Human Kinetics and Ergonomics, which allowed for the basic analysis of the data. Heart rate variability was processed from inter beat intervals in the time domain (coefficient of variability). In terms of the intervals chosen, time and frequency domain measures sampled from those obtained during the test batteries and those obtained during the period of “work” or beading. Test batteries lasted no longer than 20 minutes, while the intervals of work ranged from 40 minutes up to one hour and 40 minutes, depending on how far apart the respective test batteries were spaced. All analyses were exported to, and saved as excel documents.

3.2.3.7 Stimulus response software

An in-house Stimulus response software developed by Göbel© 2010 was used to run the tapping test, the accommodation test, the visual detection test and continuous tracking tests. Each test was modified to suit the requirements of this study within this program.

3.2.3.8 Subjective measures

In addition to cognitive performance and physiological measures, the use of subjective measures of sleepiness is common in shift work studies (Åkerstedt *et al*., 2014). Although such measures can be influenced by factors such as motivation, pre conceptions or direct manipulation (Annett, 2002), they provide a key insight into the perceived degree of sleepiness of an individual, which Åkerstedt *et al*. (2014) holds to be associated with perceived wellbeing. Subjective sleepiness specifically has been assessed through the use of a number of scales such as the Epworth sleepiness scale (Johns, 1991), which was developed to assess sleepiness as a trait, where sleepiness symptoms are more enduring. This measure is appropriate for the initial diagnosis of sleep pathologies in clinical settings (Shen *et al*., 2006). In contrast, the Standford sleepiness scale (Hoddes *et al*., 1973, as cited in Shen *et al*., 2006), the Visual analogue scale (Monk, 1989) and the Karolinksa sleepiness scale (KSS) (Åkerstedt and Gillberg, 1990) are measures of state sleepiness, used to determine the degree of sleepiness of an individual at a specific time and under a specific set of conditions (Åkerstedt and Gillberg, 1990; Shen *et al*., 2006). As such, they are most appropriate for research purposes, and more specifically, in instances where sleep is perturbed by conditions such as night shift work. For the purposes of this research, the KSS was adopted.

3.2.3.8.1 Karolinksa sleepiness scale (KSS)

The KSS (appended on p249) is a validated, 9-graded verbally-anchored scale (Åkerstedt and Gillberg, 1990) that has been extensively applied to measure instantaneous sleepiness in various shift work and sleep research contexts (Sallinen *et al*., 1998; Axelsson *et al*., 1998; Axelsson *et al*., 2004; Eriksen *et al*., 2006; Smith Coggins *et al*., 2006; Schweitzer *et al*., 2006; Santhi *et al*., 2007; Lovato *et al*., 2009; Howard *et al*., 2010; Waage *et al*., 2012; Davy and Göbel, 2013). In the current set up, sleepiness ratings were obtained from each participant prior to the start of each test battery through a verbally given rating.

3.2.4 Test battery structure

Six test batteries were scheduled throughout each shift. Due to the fact that only six participants could be tested at any one time, each condition or group was tested separately. Each test battery took 20 minutes to complete and participants were always tested in the same group / condition (detailed in Table 1) and in the same order with respect to the tests they started and ended with. The actual equipment was housed in a separate, well-lit room and included selected the following tests cognitive tests (for a detailed description, please refer to Selection of dependent variables section).

Table 1: Test battery times for all conditions during the night shift phase only (all Rolling shift times shown due to daily changes in shift start and end times). The word “Food” indicates the times at which participants in the conditions received a snack.

Test	Fixed Night	Nap Early	Nap Late	Rolling 2	Rolling 3	Rolling 4 & 5
Pre test	21h20	20h00	23h40	17h40	19h40	21h40
Shift start	22h00	20h20	00h00	18h00	20h00	22h00
Test 1	23h20 **Food**	21h00 **Food**	01h00 **Food**	18h40 **Food**	20h40 **Food**	22h40 **Food**
Test 2	01h20 **Food**	23h00	02h40	20h40 **Food**	22h40 **Food**	00h40 **Food**
Pre Nap		00h00	03h40			
Post Nap		04h00 **Food**	07h40 **Food**			
Test 3	03h00 **Food**	05h00 **Food**	08h40 **Food**	22h40 **Food**	00h40 **Food**	02h00 **Food**
Test 4	04h40	07h00	10h40	00h40	02h00	04h20
Shift end	06h00	08h20	12h00	02h00	04h00	06h00
Post test	06h20	08h20	12h00	02h00	04h20	06h00

3.2.4.1 Sleep parameters

3.2.4.1.1 Nap characteristics

As participants in the *Nap early* and *Nap late* conditions were afforded a napping opportunity in the laboratory, it was important to consider appropriate ways of gaining insights into the length and quality of these naps. In the absence of more specialised measures such as polysomnography, electroencephalography or actigraphy, napping participants were asked to report their perceived sleep length and quality upon awakening. More specifically, the perceived nap length (in minutes) and subjectively rated sleep quality (1 = poor and 5 = excellent) were determined verbally from each participant.

3.2.4.1.2 Sleep diary

In addition to sleep characteristics in the laboratory, insight into the sleep obtained outside of the laboratory was an important consideration. This is in light of the fact that early morning and night shift work is known to result in reduced sleep length and quality. Thus, information pertaining to how sleep was affected by the current study design was an important consideration which could be useful in explaining the effects of the conditions. In this study, sleep diaries were incorporated to provide insights into perceived sleep characteristics while outside the laboratory.

Participants were required to complete a 9-day sleep diary as accurately and as honestly as possible (appended on p: 250 and 251). Information relating to each participant's reported sleep length, perceived sleep quality and the number of disturbances were recorded for the five days before data collection and four days during data collection. In addition, any alcohol, caffeinated drinks or medication taken during the data collection period was recorded. Participants were required to record any napping or physical activity as well.

It was important to acquire this supplementary information, as it could be used to account for any discrepancies or inexplicable results obtained during testing. Specific to the Nap conditions, determining the duration and perceived quality of the post shift recovery sleep was important when compared to the no nap condition. Napping during night shift work has been reported to result in a reduced recovery sleep during the following day (Matsumoto and Harada, 1994; Dauret and Foret, 2004; Borges *et al.*, 2009). Reported sleep length and reported sleep quality while outside the laboratory (assessed via a 5 point likert scale, where 1 = poor and 5 = excellent) were extracted for analyses.

3.2.5 Food provision

The final consideration was the provision of food to the participants while in the laboratory. All participants were provided with regular snacks, in the form of sandwiches and other basic food stuffs, roughly every two hours (Refer to appendices which provide an overview of food choices: p254) and when participants consumed food: p252). Due to the staggered nature of the test batteries for the different conditions (outlined in Table 1, above), the participants were not provided with food during their scheduled breaks, but immediately after completing specific test batteries.

More specifically, the *Rolling rotation* and *Fixed night shift* conditions received food after their first, second and third test batteries, while the two nap groups had the opportunity to eat after their first test battery, after the nap and after the third test battery (Table 1). This meant that the effects of the food consumption would not have an immediate impact on participant alertness during the test battery that followed. This method of food distribution also meant that eating did not always coincide with break opportunities. In this case, participants just ate at their work stations while beading.

It is acknowledged that although the effects of food consumption at night may confound the outcome measures, it was necessary to offer food regularly to negate the effect of hunger on mood and general levels of physiological arousal. Furthermore, owing to the taxing nature of the data collection schedule, the inclusion of regular, decent sustenance was important for the retention of participants, an assertion supported by previous research (Signal *et al*., 2012). Those who did not wish to eat were not forced to and were offered food at the next meal opportunity.

3.2.6 Statistical hypotheses

In light of the abovementioned experimental design and set up, which aimed to:

- Determine the effects of a gradual introduction into the night shift and
- Determine the effects of an extended nap opportunity combined with a split shift

on various cognitive performance, physiological, perceptual and sleep responses under simulated night shift conditions, the statistical hypotheses were as follows:

3.2.6.1 Time of day effects

Although the focus of the current investigation was the effects of the different conditions, an appreciation of the sensitivity of the outcome measures to time of day effects was an important point of departure. As such, the Null hypothesis states that the performance, physiological and subjective sleepiness measures will not differ significantly over each night shift measured during the six different test batteries (irrespective of the different conditions)

HO: µMeas(Time1)= µMeas(Time2)= µMeas(Time3)…..=µMeas(Time6)

HA: µMeas(Time1)≠ µMeas(Time2)≠ µMeas(Time3)…..≠µMeas(Time6)

Where:
Meas = performance, physiological, subjective and sleep measurements included
Time = refers to one of the six test batteries applied each night shift

3.2.6.2 Cumulative effects (Day effect)

In addition to gaining insights into the effects of the time of day, an understanding of any cumulative effects associated with working night shifts on the outcome measures was important. In this case, the Null hypothesis states that the performance, physiological, subjective sleepiness and sleep measures will not differ significantly over the four consecutive days of working night shifts.[4]

HO: µMeas(Shift 2)= µMeas(Shift 3)= µMeas(Shift 4)=µMeas(Shift 5)

HA: µMeas(Shift 2)≠ µMeas(Shift 3)≠ µMeas(Shift 4)…..≠µMeas(Shift 5)

Where:
Meas = performance, physiological, subjective and sleep measurements included
Night = refers to one of four night shifts that each participant completed

3.2.6.3 General condition effects

The Null hypothesis states that there will be no differences in the responses to all measured variables (performance, physiological, subjective and sleep) between all experimental conditions (the *Rolling rotation* condition, the *Nap early* and *Nap late* conditions and the *Fixed night* condition) generally during the four night shifts.

$$\textbf{HO: } \mu\text{Meas.(Condition)}_{FN} = \mu\text{Meas.(Condition)}_{RR} = \text{Meas.(Condition)}_{NE} = \text{Meas.(Condition)}_{NL}$$

$$\textbf{HA: } \mu\text{Meas.(Condition)}_{FN} \neq \mu\text{Meas.(Condition)}_{RR} \neq \text{Meas.(Condition)}_{NE} \neq \text{Meas.(Condition)}_{NL}$$

Where:
General condition = any observed difference between the conditions generally during the remaining four night shifts, irrespective of time or day effects.
FN = Fixed night shift

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[4] The first afternoon shift served as an extended habituation. As such, it was not included in the statistical hypotheses. More details about the relevance of the afternoon shift and the responses therein is included at the start of Chapter 4.

RR = *Rolling rotation*
NE = Nap Early
NL = Nap Late

3.2.6.4 Other effects of interest

3.2.6.4.1 Condition and time interaction

In addition to determining any general differences between the four experimental conditions, an understanding of whether the conditions altered the responses during each shift was important. This stems mainly from previous research in which the inclusion of napping has either improved alertness and performance or caused decrements as a result of sleep inertia. Although not specific to the napping conditions, it was of interest to understand whether any of the conditions altered the performance, subjective and physiological responses during each shift (over time).

3.2.6.4.2 Condition and day interaction

Finally, the effects of the four different experimental conditions on the abovementioned responses over the four consecutive night shifts were also explored. This was important given the fact that previous research has highlighted an increased risk of cumulative sleep loss as a result of working consecutive night shifts, which has in turn been linked with cumulative decrements in cognitive performance, altered physiological responses and increasing sleepiness.

3.2.6.4.3 Covariates

As both male and female participants were included in the study, differences with respect to sex were also analysed. This served mainly as a means of controlling for unexplained variance.

3.2.7 Pre experimental preparations

Prior to the recruitment of the potential participants and the commencement of any form of data collection, ethical clearance was obtained from the Department of Human Kinetics and Ergonomics ethics committee.

3.2.7.1 Recruitment of participants

Participants were sourced from, but not limited to the Rhodes University student population and were recruited through advertisements in various University media (Advertisement is appended on p239). Male and female participants, between the ages of 18 and 26 years were eligible to participate. Although it is well accepted that there are differences in the way that males and females respond to night shift work (Saskvik *et al*., 2011), both sexes are involved in night work which warranted both being included in the study. Other criteria, which were made explicit in the advertisements, included:

3.2.7.1.1 Non-smokers

Nicotine contained in cigarettes or patches has an arousing effect and has been found to improve attention, working memory performance and concentration (Kumari *et al*., 2003) which may confound the measures within the current study. Furthermore, there would also be practical limitations associated with participants having to stop work to smoke, which would interfere with the work task and / or testing.

3.2.7.1.2 No sleep disorders

These include disorders such as insomnia, sleep apnoea, excessive daytime sleepiness, restless leg syndrome and the like. Not only would the presence of a sleep disorder confound participant responses during experimentation, but the nature of the data collection may potentially aggravate the effects of the disorder further (as indicated previous studies: Lamond *et al*., 2003; Kubo *et al*., 2010; Signal *et al*., 2012).

3.2.7.1.3 No prior shift work experience or chronodisruption

Participants should not have participated in any form of permanent or rotational shift work in the last year or travelled across more than two time zones within the preceding two months (Mollicone *et al*., 2008).

3.2.7.1.4 Good physical health

Participants had to be in good physical health prior to experimentation (as suggested by Lamond *et al*., 2003; Kubo *et al*., 2007; Signal *et al*., 2012). Additionally, participants had to have a fairly consistent sleeping pattern with reference to bed and rising times, while also obtaining on average, seven to eight hours of sleep per night. Participants could not be on any medication that caused drowsiness or promoted sleep or, alternatively, increased arousal or mood or concentration (such as Ritalin or Concerta). These medications would affect alertness levels differently during the experimentation.

Participants received remuneration to the value of R550 for their time in the laboratory. Participants who chose to leave the study before it ended were paid an hourly rate for the time they had completed before leaving.

3.2.7.2 Habituation

Interested participants attended an introductory session one week prior to the commencement of the data collection period. The aims and objectives and all other relevant information pertaining to the different conditions and dependent variables were explained in detail, in both written and verbal formats (contained in a Letter to the participants: p241). Lastly, any potential risks to the participants were made explicit and any questions were answered by the primary researcher. Thereafter all individuals were given the chance to leave the session if they were no longer interested in participating.

The students that remained were presented with an informed consent form to sign (p245) with the express understanding that they were free to discontinue their involvement in the data collection at any stage without prejudice. Thereafter, participant age, sex and contact information was obtained, and each individual completed the Morningness-eveningness questionnaire (MEQ: Horne and Östberg, 1976: p246). The MEQ is comprised of 19 questions that aim to determine the respondent’s preferred time (of the day) to be active. Scores obtained from this multiple choice questionnaire range between 16 and 86, with lower scores being associated with evening types (Horne and Östberg, 1976). Prior to leaving each participant was presented with the standard Sleep diary (p250 and p251), which required them to keep a detailed record of their sleep wake habits for five days prior to experimentation and for four days during the data collection period.

A second habituation session was scheduled the day before the start of data collection. Participants arrived at the laboratory in their allocated conditions; in total, there were six people in the laboratory at any one time. Participants were introduced to the laboratory environment, the task requirements as well as the test battery. In their groups, they completed the whole test battery at least three times (or more if they felt they were not comfortable with the measures). This session provided insights into how the participants would rotate between the tests, the duration and requirements of each test.

Thereafter, each group were reminded of the pre data collection requirements (see letter to the participant) and informed what time they needed to arrive the next day. All participants were instructed to arrive at staggered times before the designated start of the first shift, which was an afternoon shift (A detailed overview of the testing arrangement for each condition is appended on p238).

3.2.7.3 Participant characteristics

At the start of the data collection 24 males and 24 females were recruited to participate. After the first shift, three male participants (one from the *Fixed night* condition, one from the *Nap early* group and one from the *Rolling rotation* condition) withdrew from the study. In addition, one male in the *Fixed night* completed all the shifts except for the last one due to illness. As such, this data was also excluded from the analysis. For the remainder of the shifts, 20 males (with a mean age of 21.6 ±1.64) and 24 females (with a mean age of 21.17 ±1.54) completed all the required tests.

3.2.7.3.1 Chronotype

The inclusion of the MEQ facilitated the equal distribution of the different chronotypes among the four different experimental conditions. Allocation to the different conditions was also based on sex and age (Table 2). This allocation was not random as the balancing of these groups was important to minimise any confounding effects of these abovementioned variables on the outcomes measures.

Statistical analyses revealed no significant differences with respect to the distribution of age (*p=0.82*) and chronotype (*p=0.11*) across the conditions (Table 2). Apart from these analyses, age and chronotype were not used in any additional analyses as covariates. While chronotype has been identified as a factor that may affect tolerance to night shift work, it's effect could not be assessed as the number of participants in each chronotype category was unbalanced (Table 2) . This may have produced invalid results and erroneous interpretations about the effect of chronotype in this study. The effects of unbalanced males and females in the *Fixed night*, *Nap early* and *Rolling rotation* conditions could not be avoided as data collection had already begun when the participants withdrew.

Table 2: Distribution of sex, age and chronotype across the four experimental conditions. **FN**: *Fixed night* condition; **RR**: *Rolling rotation* condition; **NE**: *Nap early* condition; **NL**: *Nap late* condition. ♂ = males, ♀ = females.

	FN		**NE**		**NL**		**RR**	
Sex (n)	6 ♀	4 ♂	6 ♀	5 ♂	6 ♀	6 ♂	6 ♀	5 ♂
Age	21.1 yrs		21.7 yrs		21.4 yrs		21.2 yrs	
Morning type (n)	0		0		0		0	
Moderate Morning type (n)	2		1		0		2	
Intermediate (n)	7		8		8		7	
Moderate Evening type (n)	1		2		3		2	
Evening type (n)	0		0		1		0	

3.2.8 Experimental procedures: data collection phases

The data collection was split into two, identical phases. The first occurred in September 2012 and the second in April 2013. This was due to the fact that only 24 participants could be accommodated at any one time. Furthermore, these two phases occurred in different laboratories: this could not be avoided as one of the laboratories was a sanctioned pharmaceutical testing facility, which was available for the September data collection, but not for April. The second phase was housed in the Department of Human Kinetics and Ergonomics. The general conditions within each laboratory were made as similar as possible with respect to lighting and temperature and the test set up and shift arrangements remained the same.

3.2.8.1 Test battery structure

Essentially, each test battery was comprised of two parts. The first, which took place in the actual working area, involved assessing beading performance (total beads used between test batteries), tympanic temperature and subjective sleepiness. While participants were seated, each participant’s tympanic temperature and subjective sleepiness was recorded, before the mass of the beads they had used was determined by the @HOME Digital platform scale (mass threshold of 1 gram).

Following these initial measures, the participants (grouped by the condition to which they were allocated) entered the main testing area, which was a well-lit room, separate from the work and resting areas. One condition was tested at a time. In total, participants had to complete seven separate tests on six separate work stations (illustrated in Figure 16 below), namely the accommodation test, the visual detection test, the object recognition test, the simple reaction time test, the working memory test, the tapping test and the continuous tracking test . Each participant started each test battery with the same test and completed the remaining tests in the same order.

Additionally, each participant also started with the same level of difficulty during each test where applicable, while the order in which the two levels of difficulty of the tests was randomised between different participants in each group. In total, it took each condition 20 minutes to complete all of the tests, after which participants returned to their bead work. Prior to a group leaving the testing area, the next group had already undergone the initial pre-test battery measures and left the working area when the testing area became available. This procedure was consistently applied during all shifts and for all conditions.

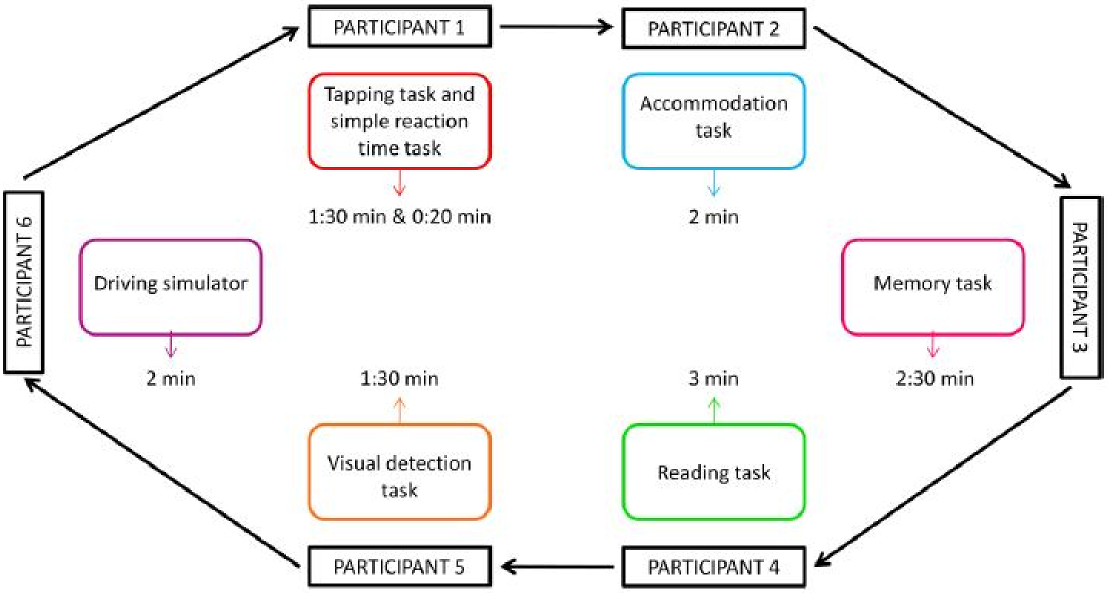

Figure 16: Layout and organisation of the test battery applied (Adapted from Huysamen, 2014). Pre-test battery measures of beading performance, tympanic temperature and subjective sleepiness are not shown.

3.2.8.2 Procedures for the Afternoon shift

The data collection period commenced with an afternoon shift, which was scheduled from 14h00 to 00h00. The participants from the all conditions except the *Rolling rotation* arrived between 13h00 and 13h40 before the scheduled 14h00 start on the first shift. The *Rolling rotation* only arrived at 15h40, for a scheduled start of 16h00 (two hours after the first three conditions). This two-hour difference arose from the fact that the intervention, that is the gradual transition into the night shift, started during the first shift. Although this meant that the *Rolling rotation* group started at a different time compared to the other conditions, this was the compromise that was decided upon. It ensured that by the fourth shift, the *Rolling rotation* condition would be operating on the same shift times as the *Fixed night* condition.

Upon arrival, each participant was fitted with the Suunto® heart rate detection belt and the time at which it was fitted was recorded. Thereafter, participants from the respective conditions completed a 20-minute pre-test battery in a staggered manner, after which they sat quietly and conversed before the start of the shift. Once the shift had started, all participants were seated in the same working area and were required to perform the simple beading task, while also being permitted to socialise under the supervision of a research assistant. Apart from the first on-shift test (the first of which started 40 minutes after the start of the shift) each group was tested roughly every two hours. In total, there were four on-shift tests. Prior to leaving the laboratory, each group completed a post shift test battery. For the *Nap early, Nap late* and *Fixed night* conditions, this occurred between 22h00 and 23h00. As the *Rolling rotation* group arrived two hours later than the other groups, their post shift test occurred at 00h00.

3.2.8.3 Procedures for Night shift

The second day of experimentation marked the start of the night shift work period. This also meant that the start times for each condition were even more staggered. Prior to undergoing any testing, all participants were fitted with a Suunto® memory belt, which was worn for the duration of the shift.

3.2.8.3.1 Rolling rotation

For this condition, the shift start and end times changed each day for four out of the five shifts that experimentation was held; participants arrived and left the laboratory two hours later. This was the case up until the fifth shift, when the timings were the same as the fourth day (and that of *Fixed night* condition). Similar to the *Fixed night* condition, the *Rolling rotation* were provided with three, evenly spaced 15-minute breaks throughout each 8 hour night shift (Table 3). As mentioned previously, food was also provided after the first, second and third on shift tests, if the participants requested it (Table 1, p91).

Table 3: Break times for all conditions during the night shifts only. Breaks for **FN** and **RR** were 15 minutes, while break in the Nap early and Nap late conditions were 22.5 minutes. (Where **FN** = *Fixed night* condition **NE** = *Nap early*, **NL** = *Nap late* and **RR** = *Rolling rotation*.

	FN	**NE**	**NL**	**RR**		
	All nights			**Night 1**	**Night 2**	**Night 3 & 4**
Break 1	23h40	21h40	01h40	19h40	21h40	23h40
Break 2	01h40	05h40	09h40	21h40	23h40	01h40
Break 3	03h20			23h40	01h40	03h20

3.2.8.3.2 Nap early condition

The *Nap early* condition also completed four consecutive eight-hour night shifts. However, the group spent a total of 12 hours in the laboratory; shifts began at 20h20 (following a pre shift test) and ended at 08h20. Unlike the *Rolling rotation* or *Fixed night* conditions, this group's 8-hour shift was split into two, four-hour long work periods (Period 1 = 20h20 to 00h20; Period 2 = 04h20 to 08h20). During each work period, one break of 22.5 minutes permitted participants to leave the work area. The two work periods were separated by four hours, during which napping was encouraged.

Prior to the nap, a pre nap test was completed after which heart rate detection devices were removed from the participants to limit any discomfort. In total, participants could nap for three hours and 20 minutes with male and female participants being separate. Instructions were provided in that if, after approximately one hour a participant was unable to sleep, they were permitted to return to the testing area. In all cases, this did not occur.

At 03h40, a research assistant gently woke the participants with name calling. Thereafter, each participant was given 20 minutes during which to "gather" themselves (03h40 to 04h00). Additionally, during this period, pre ordered food was made available, after which the perceived sleep length and sleep quality for the nap was obtained. The post nap test battery began at 04h00, with participants returning to work at 04h20. In this condition, the pre nap test was considered "working time" as it fell within the first four-hour work period. The post nap test however, did not and therefore was not counted as working time. With respect to food provision, this group were offered food after their first on shift test (21h20), immediately after the nap (03h40) and after their third on shift test (05h20).

3.2.8.3.3 Nap late group

With respect the later nap group, four, consecutive eight hour shifts were completed, with the group also spending 12 hours in the laboratory in total. The organisation for this condition was exactly the same as the *Nap early* condition, the only difference was the shift timings; shift began at 00h00 (following a pre shift test at 23h40), with the first work period being scheduled between 00h00 and 04h00 and the second between 08h00 and 12h00. Prior to napping, a pre nap test was completed (at 03h40), after which, participants could nap for three hours and 20 minutes. The same procedures with respect to the *Nap early* condition were applied to this group. At 07h20, participants were awakened, given the 20-minute recovery period and food (if requested) before completing a post nap test at 07h40 and returning to work at 08h00. Each four-hour work period had two on shift tests and a 22.5-minute break, and food was provided after the first on shift test (01h20), immediately after the nap (07h20) and after the third on shift test (09h00). These are illustrated in Table 1.

3.2.8.3.4 Fixed night condition

The *Fixed night* condition completed four consecutive night shifts, which started at 22h00 and finished at 06h00. Three evenly spaced 15-minute breaks were scheduled during each eight hour shift, the times of which are illustrated in Table 3. Participants left their workstations and took these breaks in another room, where they were permitted to read and socialise under the supervision of a research assistant. Napping was not permitted at any time. As was the case with the afternoon shift organisation, the group were provided with food immediately after their first, second and third on shift tests. The timings for each test battery for the *Fixed night* condition remained consistent over the four night shifts as well.

3.2.9 Post shift

At the end of each shift, participants completed the post shift test battery. Participants were encouraged to go straight home and to attempt to sleep for as long as possible. They were also requested to complete the relevant sleep information in the sleep dairies and to consider the restrictions with respect to caffeine and other stimulants, alcohol and physical exercise.

3.2.10 Statistical analyses

Data from all tests and measures were reduced and imported into Microsoft excel. Missing data were managed through extrapolation, achieved by determining the average between the two data points adjacent to the missing data cell. If this was not possible (as was the case for the first and last tests of each shift), then the last observed data point was imputed so as not to add any variance.

The data were then treated and analysed in three different ways to determine which delivered the clearest results. The first set of analyses used just the raw data. The second and third analyses were performed on normalised data, which removed factors that contributed to variance in the data. The data were normalised in two different ways. Firstly, data were referenced to the average of the four on shift tests (Test 1, 2, 3 and 4) for each individual on the first shift to limit the influence of each individual's variance. The second normalisation treatment involved referencing all data to the group (condition) average of the four on shifts tests during the first afternoon shift. Following analyses using the Statistica software package, version 11 (Statistica, Statsoft, Inc.; Tulsa, Oklahoma, USA), where parametric tests were applied (discussed in more detailed below) it was deemed that the raw data produced the most stable results when compared to the two other sets of data that had been normalised (despite the general trends being similar). As such, the results presented in Chapter 4 are those obtained from the analyses of raw data for all measures.

Initially, analyses focused on the responses during the first afternoon shift, which served as an extended habituation. A two factorial analysis of variance (ANOVA) was used for this. This served as a means of testing the homogeneity of responses between the different conditions prior to the start of the night shift testing phase and the experimental interventions. Thereafter, a three-factorial ANOVA was applied to determine the general effects of the independent variables during the remaining night shifts. All relevant statistical effects are outlined at the start of Chapter 4. Although the experimental conditions occurred at different times of day, all data were analysed as if the conditions occurred at the same time of day, a technique that has been applied previously (Jackson *et al*., 2014). Although this was a limitation, when the data were interpreted, the differences between the conditions with respect to time of day (and the associated differences in sleep pressure and time on task) were considered.

In all analyses, sex was considered as a categorical covariate. Sex warranted inclusion owing to the differential effects that night shift work has on males compared to females. While its inclusion in the analyses was important to control for unexplained variance, the comparison of male and female participant responses was peripheral to the study. Furthermore, the sample size for each sex group was small, which limits the generalisability of the findings to the general population. Therefore, its effects are noted, but not discussed. Tukey post hoc tests were also applied. All statistical responses were set at an error probability of $p \leq 0.05$.

CHAPTER 4: RESULTS

4.1 INTRODUCTION

This chapter will present the results of the statistical comparison of the effects of the *Rolling rotation,* the two nap conditions (*Nap early* and *Nap late*) and the *Fixed night* condition. The first section provides an overview of the key statistical considerations for the interpretation of the results. Thereafter, a summary of the effects observed during the first afternoon shift is presented. During this shift, working time was similar across all the conditions, and thus served as an extended habituation for all the participants in the different conditions. Analyses of this first shift aimed to assess the homogeneity of the participant responses in each condition's prior to starting the night shifts and the different experimental conditions. This way, differences observed during the night shift phase could be attributed to the effects of the different experimental conditions, and not differences between the groups.

Thereafter the focus shifts to the presentation of the effects of the different experimental conditions during the four proceeding night shifts, which was the main focus of this study.

Following the application of the three-factorial ANOVA with sex as a covariate, a number of effects are presented and subsequently discussed. In addition, due to the rather excessive time commitments placed on each participant (+40 hours in five consecutive days), the number of participants that could be accommodated in each condition was limited to 12. This fact may have compromised the power of the inferential statistics applied in this study. As such, and in addition to presenting results that satisfy the significance criterion of $p<0.05$, results with error probabilities of between 5 and 10% ($p<0.5$ but less than 0.1) were highlighted, not as significant results, but as potential points of interest for similar research in the future. These will be elaborated upon in the discussion section.

4.1.1 Statistical considerations

The italicised words below will refer to the following in the results section.

Condition effect: a general difference between the night shift conditions over the four night shifts, irrespective of time of day or day effects.

Time effect: observed differences between subsequent tests during the night shift phase (irrespective of day or condition effects). This effect reflects the interaction between the circadian-modulated reductions in physiological alertness during the night, increasing sleep pressure as a consequence of extended wakefulness and the effects of time on task.

Day effect: observed differences in outcome measures between the subsequent shifts tested (irrespective of condition or time effects). Such an effect is assumed to reflect the effects of the adaptation to a different sleeping regime and/or the cumulative effects of sleep loss over the consecutive shift.

Condition by time effect: effects of the night shift conditions on the subsequent tests during the night shift. More specifically, this reflects the different shift type effects on the circadian and homeostatic-related changes in performance or alertness over the course of each shift.

Condition by day effect: effects of the night shift conditions on the responses over the course of the four night shifts. This could either reflect how the conditions contribute to cumulative sleep loss (and the associated decrements in alertness and performance) or how they aid in the adaptation to the night shift conditions.

Final effect: any observed differences between the four experimental conditions during the last two night shifts. This provided insights into effects of the experimental conditions towards the end of the data collection phase. This was particularly important as it coincided with the *Rolling rotation* condition assuming the same shift times as the *Fixed night* condition.

Sex effect: observed differences between male and female participants in the study, irrespective of condition, time of day or shift effects.

Table 4: Overview of statistical tests applied. Not shown here are post hoc tests (Tukey), which were applied where appropriate.

Purpose of inclusion		**Effect (factors)**	**Statistical method of Analysis**
GROUP HOMOGENEITY TESTING (Afternoon shifts	Identify any differences between groups prior to the start of night shifts and the interventions	***Condition***	Two factorial ANOVA with one covariate
		Condition x Time	
GENERAL EFFECTS (Night shifts)	Determine the validity of the dependent variables to measure the effects of the night shift	***Time***	Three factorial ANOVA with one covariate
	Determine the main and interaction effects during the four night shift phase	***Days***	
		Condition	
		Days x Condition	
		Time x Condition	
		Days x Time	
		Days x Time x Condition	
		Sex (Covariate)	
FINAL EFFECT (Last two night shifts)	Determine the main and interaction effects during the final two night shifts when the Rolling rotation and the Fixed night shift operated on the same shift timings. Analyses included both nap groups as well.	***Time***	Three factorial ANOVA with one covariate
		Days	
		Condition	
		Days x Condition	
		Time x Condition	
		Days x Time	
		Days x Time x Condition	
		Sex (Covariate)	

4.1.2 Test for response homogeniety during the afternoon shift

The first analysis focused exclusively on the afternoon shift. It was included to determine whether differences existed between the conditions prior to the start of the night shift phase and the actual interventions. Although the *Rolling rotation* group started at different times during the initial shift (due to the nature of the actual design) compared to the other conditions, a comparison of all condition was warranted to ensure that differences observed during the rest of the data collection were due to the conditions and not to participant differences. Only general condition and condition by time interaction effects were focused on as these were the most relevant to determine if any differences existed between the different conditions. All the relevant statistical data tables are available as Appendices (p252).

Table 5: Statistical effects observed during the first shift which was similarly arranged for all conditions. * = $p<0.05$. # = $p<0.1$. ns = $p>0.1$. The table includes the actual dependent variable, the two levels of difficulty (where appropriate) and the outcome measure derived from each dependent variable.

Type of variable	Dependent variable	Difficulty	Outcome measure	Condition	Condition x Time
Performance	**Beading task**	–	*Beading performance*	ns	**$p<0.01$**
Visual perception measures	**Accommodation test**	–	*Accommodation time*	ns	ns
		–	*Choice reaction time*	ns	ns
	Visual detection test (VDT)	80 distractors	*Median reaction time*	ns	**$p<0.01$**
		40 distractors	*Median reaction time*	$p=0.06$	ns
		80 distractors	*% of stimuli overlooked*	ns	ns
		40 distractors	*% of stimuli overlooked*	ns	ns
	Objection recognition / reading test	Low resolution	*Processing/reading speed*	ns	ns
		High resolution	*Processing/reading speed*	ns	**$p=0.04$**
		Low resolution	*% errors identified*	ns	**$p<0.01$**
		High resolution	*% errors identified*	**$p=0.05$**	ns
	Simple reaction test	–	*Median reaction time*	ns	ns
Cognitive measures	**Working memory digit recall test**	Long delay	*% correctly recalled*	ns	ns
		Short delay	*% correctly recalled*	ns	ns
Psychomotor measures	**Tapping test**	–	*Motor programming time*	ns	ns
		–	*High precision Response time*	ns	$p=0.08$
		–	*Low precision Response time*	ns	ns
	Continuous tracking test	High sensitivity	*Median reaction time*	ns	ns
		Low sensitivity	*Median reaction time*	ns	ns
Physiological	**Tympanic temperature**	–	*Body temperature*	ns	ns
Subjective	**Karolinska Sleepiness scale**	–	*Subjective sleepiness*	$p=0.06$	ns

A two-factorial ANOVA revealed that for most measures, there were no significant differences between the conditions during the first afternoon shift (Table 5). However, beading output reflected a *condition by time* interaction ($p<0.01$; Figure 17), which was explained by the drop in performance in the *Rolling rotation* group towards the end of the shift, compared to the other conditions.

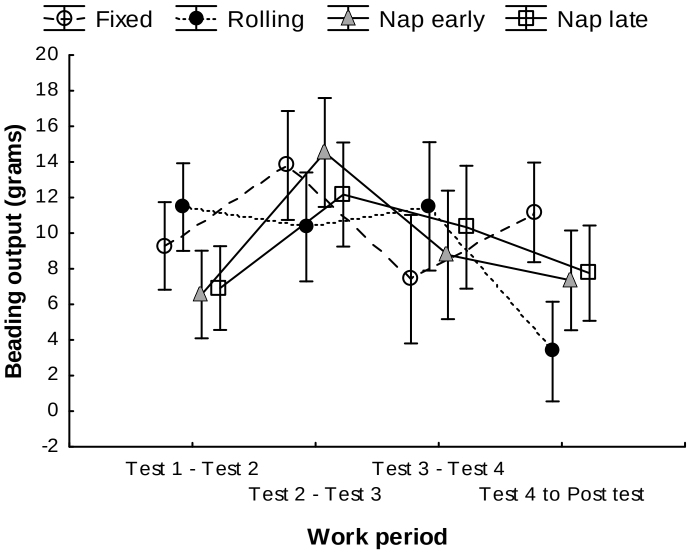

Figure 17: Mean beading performance during the first afternoon shift. Error bars denote a 95% confidence interval.

A significant *condition by time interaction* (*p<0.05*) for high resolution processing speed was indicative of the *Nap early* group's performance improving significantly relative to the *Rolling rotation* and the *Nap late* conditions towards the end of the shift (Figure 18).

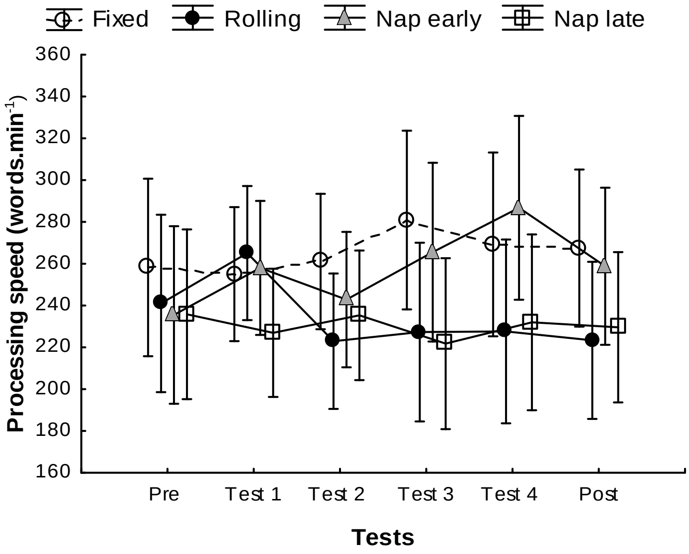

Figure 18: Mean processing speed during the high resolution object recognition test during the first afternoon shift. Error bars denote a 95% confidence interval.

The % of errors identified in the low resolution object recognition test also demonstrated a significant *condition by time interaction* (*p<0.01*): in most instances, performance improved (% of errors identified improved) in all conditions, but performance then decreased towards the end of the shift differentially for each condition (Figure 19). In the high resolution object recognition test, there was a general *condition effect*, where performance was lower in the *Rolling rotation* relative to the other conditions (Figure 20). Post hoc tests did not reveal where this significant difference was.

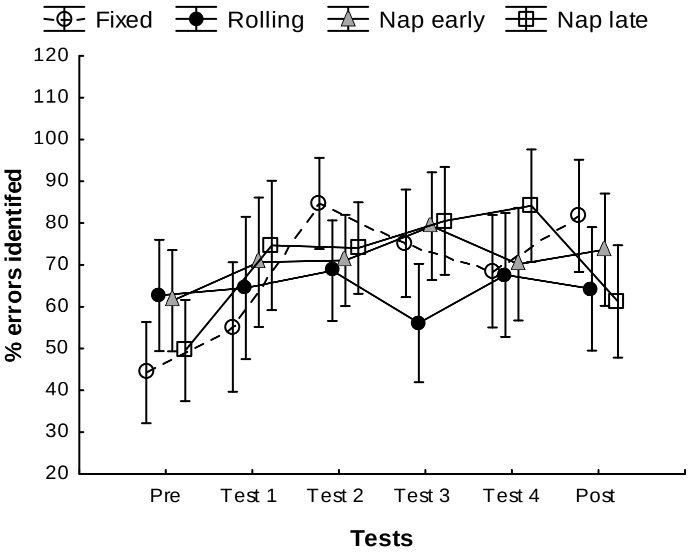

Figure 19: Percentage of errors identified during the low resolution object recognition test during the first afternoon shift. Error bars denote a 95% confidence interval.

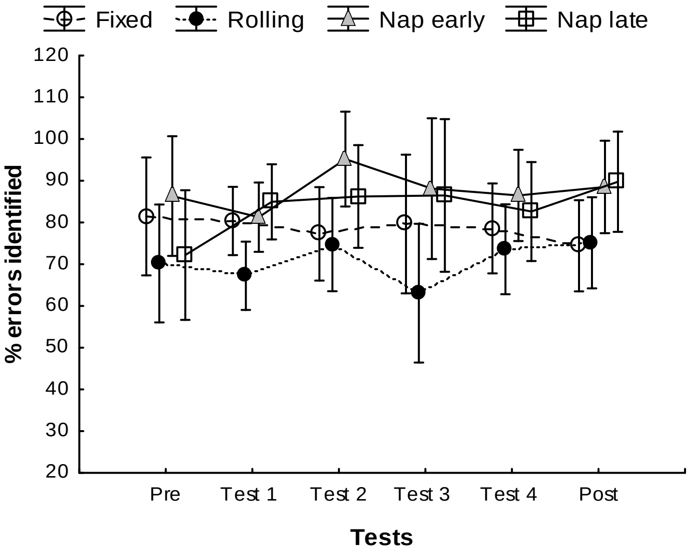

Figure 20: Percentage of errors identified during the high resolution object recognition test during the first afternoon shift. Error bars denote a 95% confidence interval.

Lastly median reaction time during the visual detection task with 80 distractors was significantly slower in the *Nap early* test 4, relative to the post test and test 4 of the *Fixed night* and *Rolling rotation* conditions respectively (*Condition by time interaction; p<0.01*; Figure 21). No other significant differences were noted.

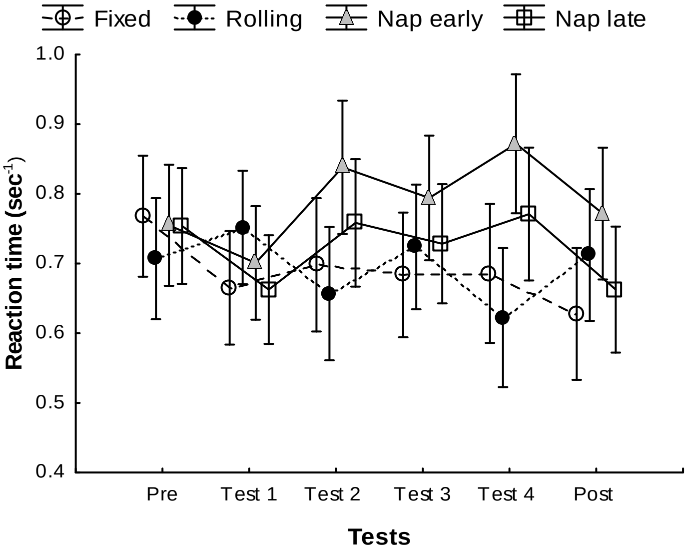

Figure 21: Reaction time during the Visual detection test with 80 distractors for all conditions during the first afternoon shift. Error bars denote a 95% confidence interval.

4.1.3 Analysis of all effects during the remaining four shifts

This section focuses on presenting the results of the responses of the different conditions during the four night shifts, while also focusing on responses during the final two shifts. All the relevant statistical data tables are available as Appendices (p260) in the same order as they appear in the results.

4.1.3.1 Performance measures

4.1.3.1.1 Beading performance

Analyses revealed a general condition effect (*p<0.05*), with a post hoc test highlighting a significant difference between *Rolling rotation* and *Nap late* specifically (Table 6 and Figure 22). Over the four shifts analysed, the *Rolling rotation* produced the highest output of beads, relative to the other conditions Additionally, beading performance increased during the second night shift, relative to the first and then decreased over the subsequent shifts (*Day effect*: *p<0.05*: Figure 23).

Performance also significantly decreased during each shift (*Time effect*: *p=<0.01:* Figure 24) with this effect differing between the conditions (*Condition by time: p<0.01*). More specifically, the *Rolling rotation* condition maintained a relatively stable output on average, apart from the final work period. In contrast, the *Nap early* group output decreased consistently over time, while the *Nap late* performance remained stable during the first three work periods and decreased during the final one. After an initial decrease in the *Fixed night* condition, performance fluctuated during the remaining work periods. A three-way interaction was found, but no real trend could be explained (*Condition by time by day: p<0.01*). There were no other main or interaction effects observed.

Table 6: Statistical effects for beading output during the night shift work period. * = p<0.05; # = p<0.1; ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	p<0.05*	p<0.01*	ns	p<0.01*	p<0.01*	p<0.05*	ns	ns
Final	p=0.052#	p<0.01*	ns	ns	p<0.01*	ns	ns	ns

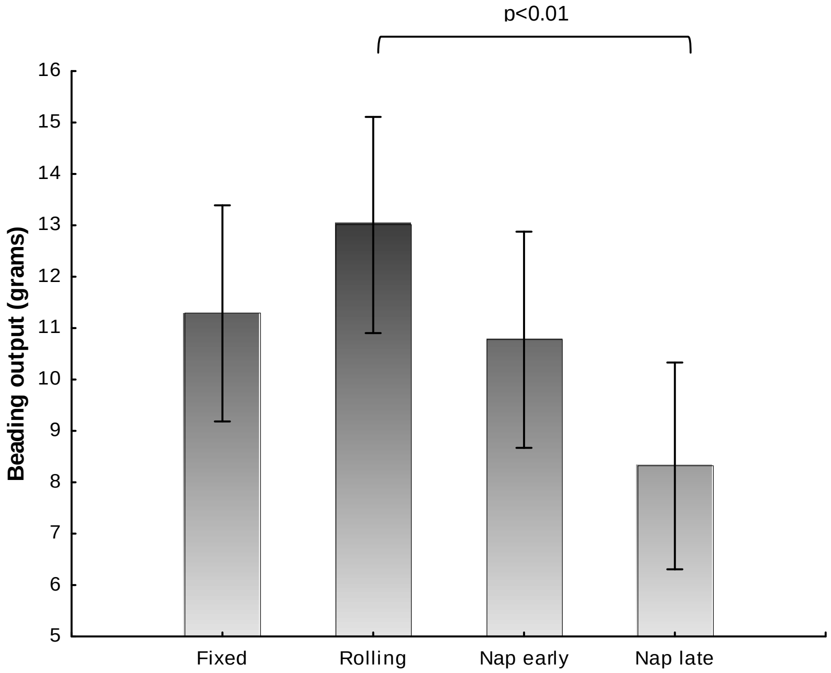

Figure 22: Mean beading output for all conditions during the four work shifts (*p<0.05*). Brackets denote a significant difference between conditions. Error bars denote a 95% confidence interval

During the final two shifts, beading output differed numerically, but not statistically between conditions, specifically between the *Rolling rotation* and the *Nap late* conditions (*p<0.052*). Furthermore, output decreased over time, with the different conditions altering the extent of this decrease in a similar way as described above and as shown in Figure 24 (*Condition by time effect*: *p<0.01*).

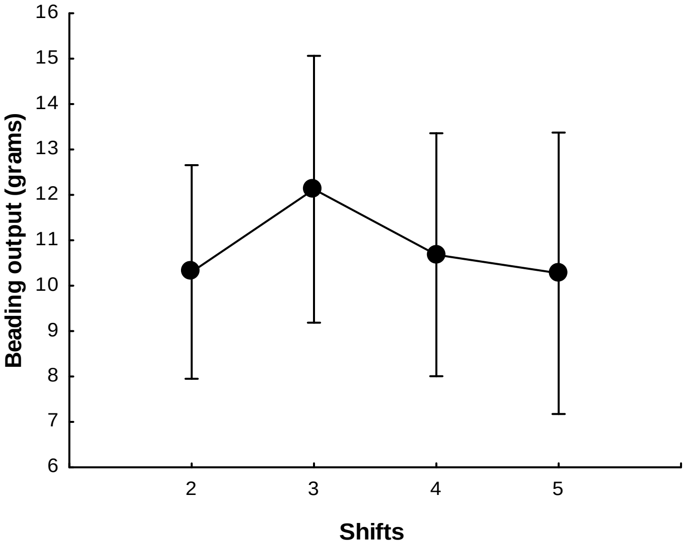

Figure 23: Beading performance over the four shifts (*p<0.05*). Error bars denote a 95% confidence interval.

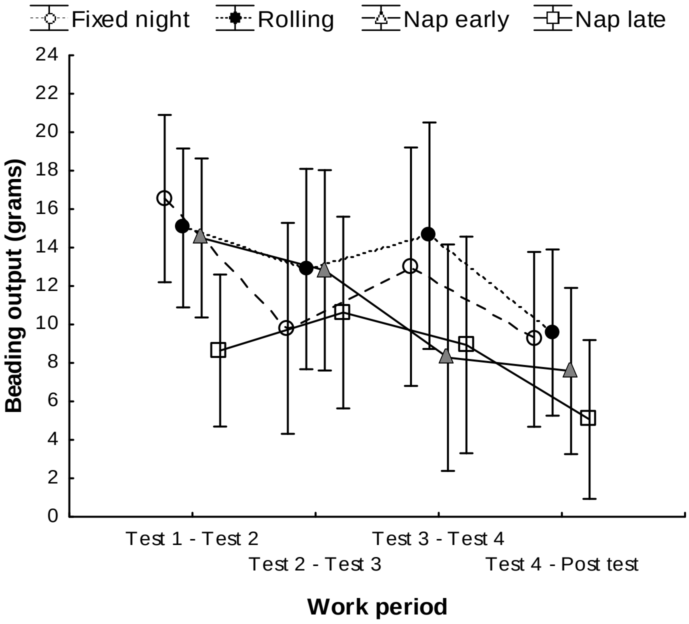

Figure 24: Beading performance over the work shift. Graph shows the responses for all four shifts over time: *p<0.01*). Error bars denote a 95% confidence interval.

4.1.3.2 Visual perceptual measures

4.1.3.2.1 Accommodation time

This outcome measure did not differ between the conditions, over the shifts or over time (Table 7). No interaction effects were observed. This was also the case during the final two night shifts when the *Rolling rotation* condition was operating at the same time as the *Fixed night shift*.

Table 7: Statistical effects for accommodation time during the night shift work period. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	ns	ns	ns	ns
Final	ns	ns	ns	ns	ns	ns	ns	ns

4.1.3.2.2 Choice reaction time (CRT)

The CRT component of the accommodation task (which was a basic decision making task) did not reflect any significant main or interaction effects between the conditions, the time of day or any adaptation or cumulative effects (Table 8). Similarly, during the final two shifts, there were no significant differences between conditions, over time or the four night shifts.

Table 8: Statistical effects for choice reaction time during the night shift work period. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	ns	p=0.06#	ns	ns
Final	ns	p=0.06#	ns	ns	ns	ns	ns	ns

4.1.3.2.3 Visual detection task 80 distractors (VDT80): Median reaction time

Reaction time to the critical stimulus during the VDT80 differed significantly over the shift cycle (*$p<0.01$*) in that reaction time improved over the four shifts (Figure 25). Furthermore, performance differed between the conditions over time, although there were no significant condition or time effects (*Condition by time: $p<0.01$*: Table 9 and Figure 26). In particular, reaction time fluctuated over time for the *Fixed night*, *Rolling rotation* and *Nap early* conditions, but improved in the *Nap late* group following the nap. During the final two night shifts, there was only a significant effect of day, in that reaction time improved during the final shift, relative to the penultimate (*p<0.01*: Table 9 and Figure 25).

Table 9: Statistical effects for reaction time (VDT: 80 distractors) during the night shift work period. * = p<0.01. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p<0.01*	ns	ns	ns	p<0.01*	ns	ns
Final	ns	ns	ns	ns	ns	p<0.01*	ns	ns

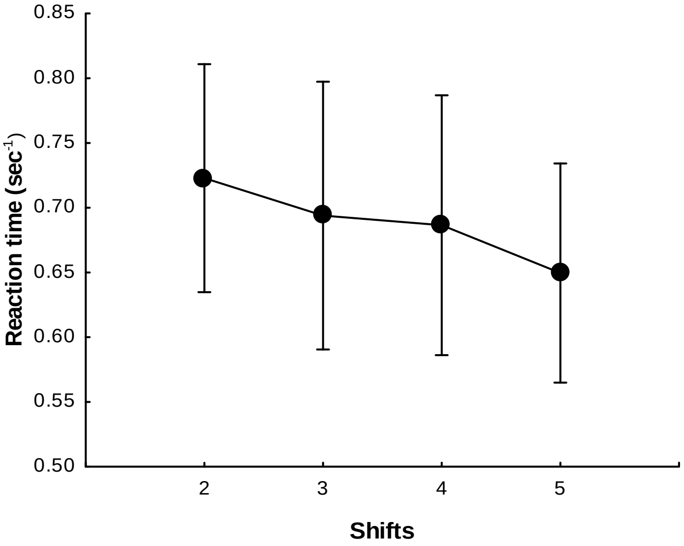

Figure 25: Reaction time (VDT: 80 distractors) as a function of the four night shifts (*p<0.01*). Error bars denote a 95% confidence interval.

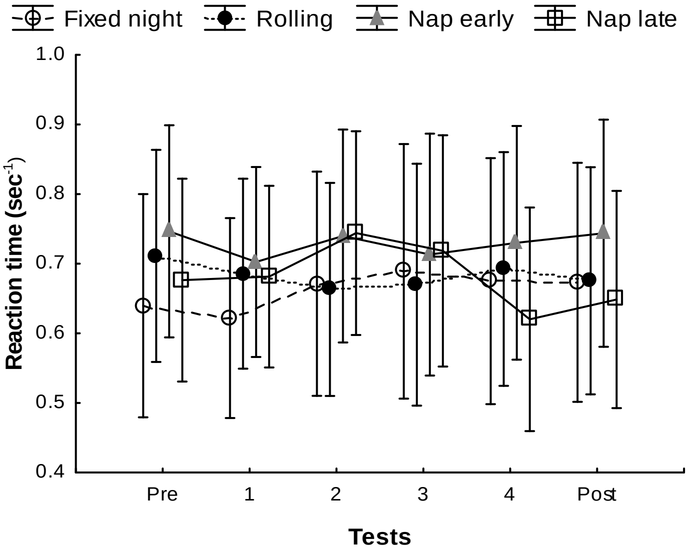

Figure 26: Reaction time (VDT: 80 distractors) over the work shift. Graph shows responses for all conditions, for four shifts over time: *p<0.01*). Error bars denote a 95% confidence interval.

4.1.3.2.4 Visual detection task 40 distractors (VDT40): Median reaction time

During this version of the test, responses did not reflect any significant effects of condition and time of day (Table 10). Reaction time did however decrease significantly over the four shifts (*Day effect: p<0.01:* Figure 27). Furthermore, although supported by an error probability of 0.051, over the four night shifts, the *Fixed night* and *Nap late* condition's vigilance performance improved, while that of *Rolling rotation* and *Nap early* conditions remained relatively consistent (displayed in Figure 28). Analyses of the final two shifts revealed a significantly better performance during the final shift, when compared to the second last one, irrespective of condition (*Day effect: p<0.01:* Figure 27).

Table 10: Statistical effects for reaction time (VDT: 40 distractors) during the night shift work period. * = p<0.01. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	ns	p=0.051#	ns	ns	p<0.01*	ns	ns
Final	p=0.09#	ns	ns	ns	ns	p<0.01*	ns	ns

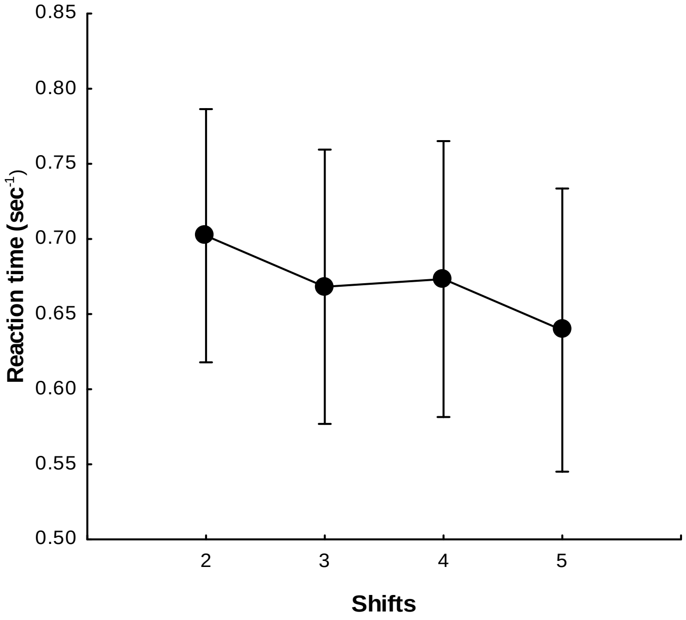

Figure 27: Reaction time (VDT: 40 distractors) as a function of the four night shifts (*p<0.01*). Error bars denote a 95% confidence interval.

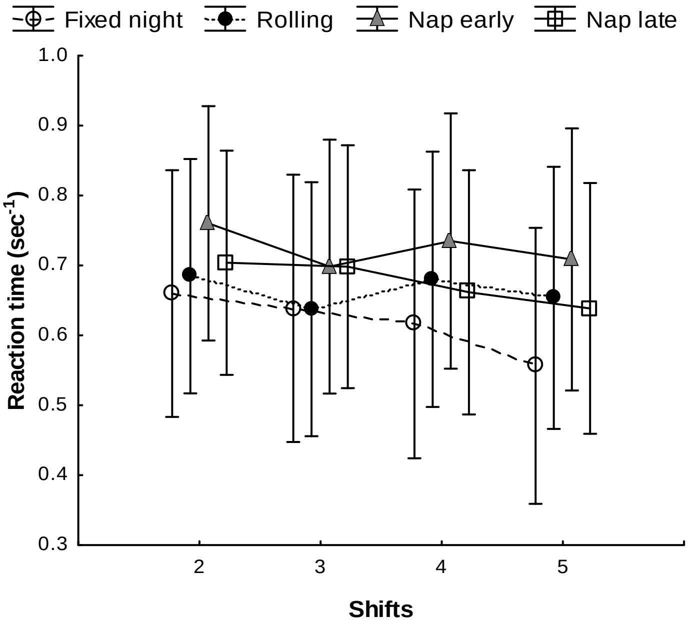

Figure 28**:** Reaction time (VDT: 40 distractors) as a function of the four night shifts. Graph shows responses for all conditions for all four shifts (*p=0.051*). Error bars denote a 95% confidence interval.

4.1.3.2.5 Visual detection task 80 distractors (VDT80): percentage of stimuli overlooked / error rate

Initial analyses revealed that there were no significant differences between the conditions, although error probability was *p=0.08* (Table 11). Post hoc tests revealed a significant difference between the *Nap early* and *Nap late* conditions in that the former overlooked more stimuli than the latter (Figure 29). The percentage of stimuli overlooked or error rate did not change over time of day, but did decrease over the four shifts (*Day effect: p<0.01:* Figure 30). No other significant effects were noted. During the final two shifts, there were no significant differences between the conditions. A time of day effect emerged in that the error rate increased significantly over the course of the shift (*Time effect: p<0.05*).

Table 11: Statistical effects for percentage overlooked (VDT: 80 distractors) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	p=0.08#	p=0.09#	ns	ns	p=0.06#	p<0.01*	ns	ns
Final	ns	ns	ns	p=0.09#	p=0.04*	ns	ns	ns

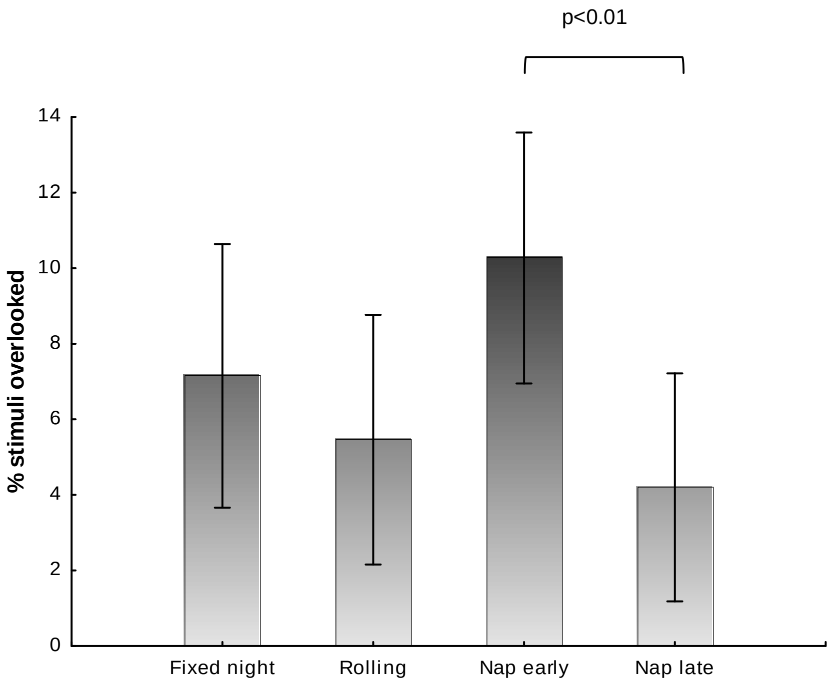

Figure 29: Percentage of stimuli overlooked (VDT: 80 distractors) for all conditions during the four work shifts. Brackets denote a significant difference between conditions (*p<0.05*) following post hoc testing. Error bars denote a 95% confidence interval.

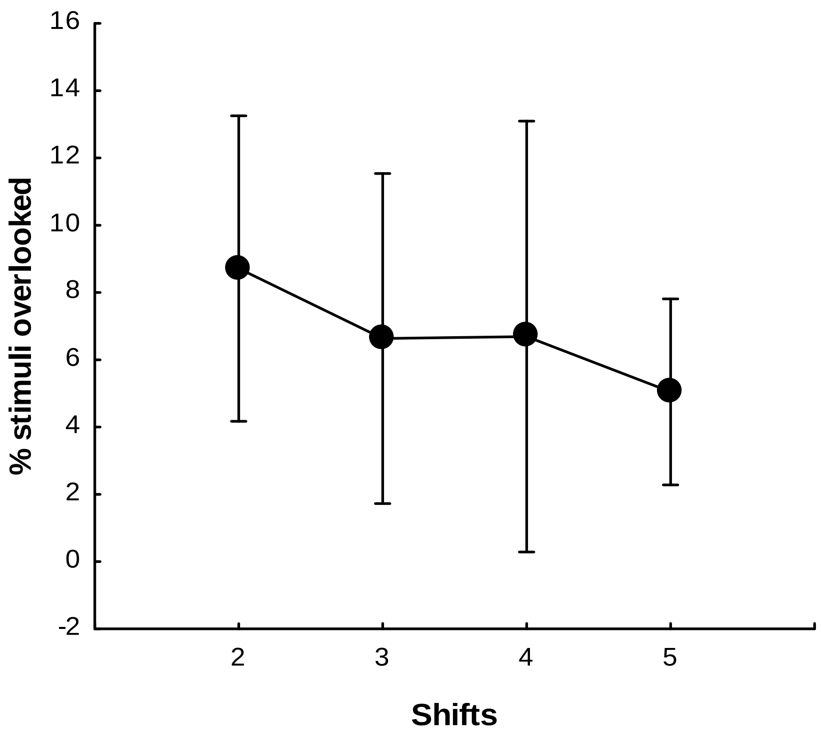

Figure 30: Percentage of stimuli overlooked (VDT: 80 distractors) as a function of the four night shifts (*p<0.01*). Error bars denote a 95% confidence interval.

4.1.3.2.6 *Visual detection task 40 distractors (VDT40): percentage of stimuli overlooked / error rate*

Analyses of the data from the easier version of VDT did not reveal any significant differences between the conditions. However, as with the more difficult version, the percentage of stimuli overlooked decreased significantly over the four shift cycle (*p<0.01)* and during the final two shifts (*Day effect: p<0.05:* Table 12 and Figure 31). Additionally, there was a significant time of day effect where performance worsened (percentage of stimuli overlooked increased) during each shift (*p<0.01*: Figure 32). There were no other general or final effects.

Table 12: Statistical effects for percentage overlooked (VDT: 40 distractors) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	p<0.01*	p<0.01*	ns	ns
Final	ns	ns	ns	p=0.054#	ns	p=0.04*	ns	ns

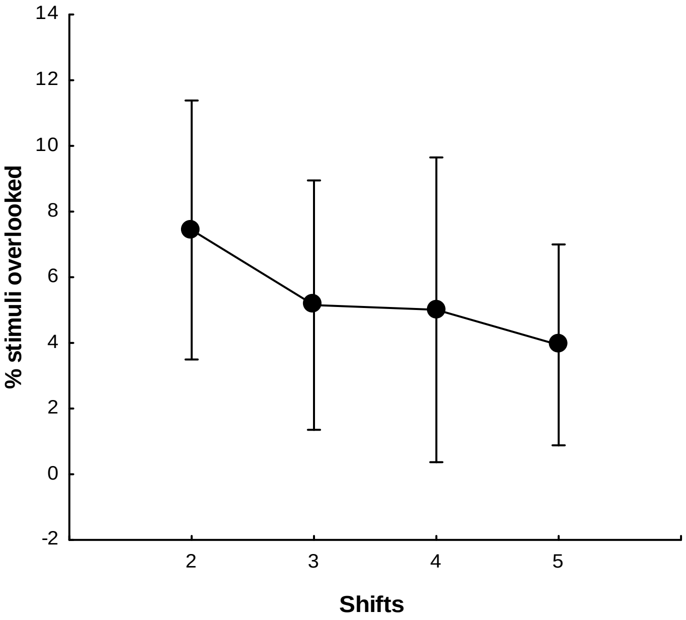

Figure 31: Percentage of stimuli overlooked (VDT: 40 distractors) as a function of the four night shifts (p<0.01). Error bars denote a 95% confidence interval.

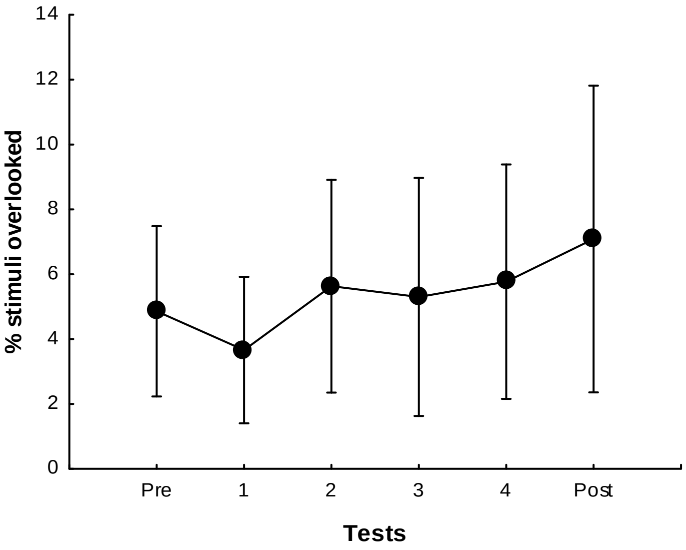

Figure 32: Percentage stimuli overlooked (VDT: 40 distractors) over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.2.7 Object recognition test (Low resolution): processing speed

Words read per minute did not reveal any significant effects of condition, day or time of day (Table 13). Apart from a *time by day* interaction from which no pattern emerged (*p<0.01*: Table 13), there were no other significant interaction effects. However, processing speed did decrease significantly during the final two shifts despite there being no difference between the conditions or between the two shifts (*Time effect*: *p<0.01:* Figure 33). The slowest processing speeds coincided with tests three and four, after which it increased during the post test.

Table 13: Statistical effects for processing speed (low resolution object recognition test) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	p=0.09#	ns	p<0.01*	ns
Final	ns	ns	ns	ns	p<0.01*	ns	p<0.01*	ns

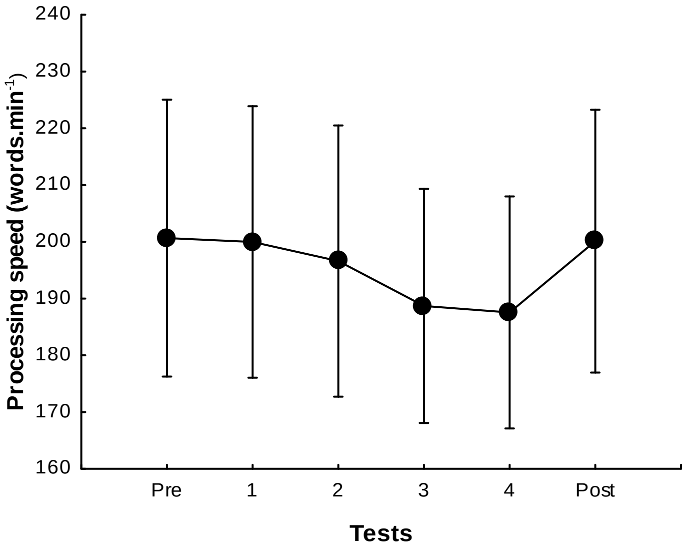

Figure 33: Processing speed (low resolution object recognition test) during the final two shifts over the work shift. Graph shows responses for final two shifts over time. Error bars denote a 95% confidence interval.

4.1.3.2.8 Object recognition test (High resolution): processing speed

During the simpler version of this test, processing speed did not differ between conditions or over the four shifts (Table 14). However, in contrast to the more difficult task, performance did significantly decrease over time of day (*Time effect: p<0.05*: Figure 34). A similar observation was made during the final two shifts (*Time effect: p<0.01*). A significant *time by day* interaction emerged, but no clear pattern of response was evident (*p<0.01*). There were no other significant main or interaction effects generally or during the final two shifts.

Table 14: Statistical effects for processing speed (high resolution object recognition test) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	p=0.01*	ns	p<0.01*	ns
Final	ns	ns	ns	ns	p<0.01*	p=0.07#	p<0.01*	ns

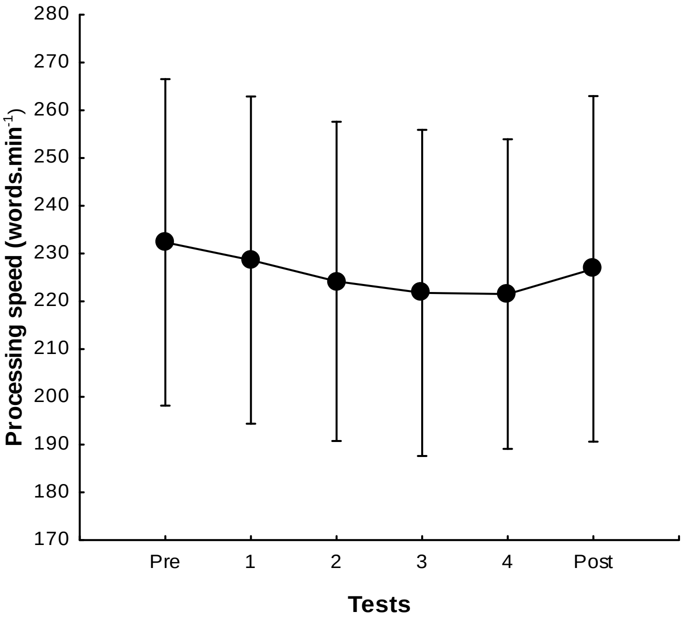

Figure 34: Processing speed (high resolution object recognition test) over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.2.9 Object recognition test (Low resolution): reliability of errors correctly identified

The identification of errors did not differ between the conditions or over time. The percentage of errors identified improved during the final two shifts compared to the first two (*Day effect*: *p<0.01:* Table 15 and Figure 35). There were no other significant interaction effects observed.

During the final two shifts, there were no significant effects of condition, time or day. There was only a time by day interaction (*p<0.01*), where error detection decreased during the penultimate shift, but remained relatively consistent and improved towards the end of the final shift.

Table 15: Statistical effects for error identification (low resolution object recognition test) during the night shift work period. * = p<0.05. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	ns	ns	ns	ns	p<0.01*	p<0.01*	ns
Final	ns	ns	ns	ns	ns	ns	p<0.01*	ns

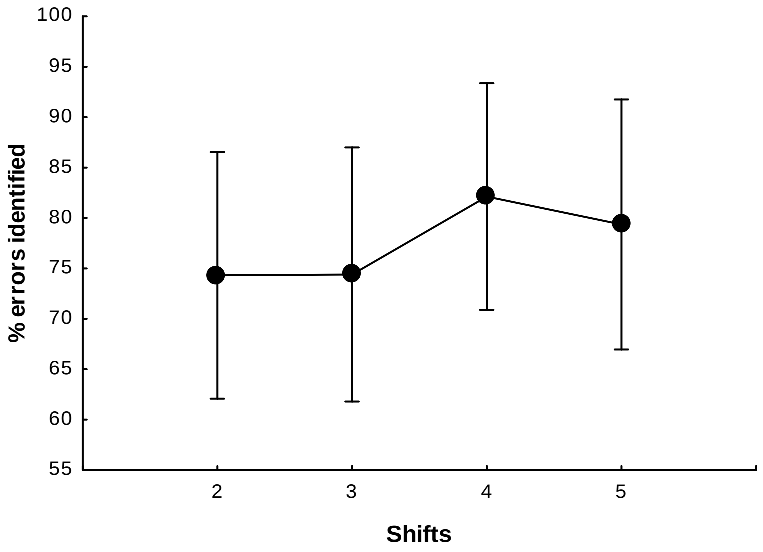

Figure 35: Reliability of errors identified (low resolution object recognition test) as a function of the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.2.10 Object recognition test (High resolution): reliability of errors correctly identified

Error identification during the easier task did not differ significantly between conditions. Like the low resolution test, the reliability of error detection increased during the latter two shifts, relative to the first two (*Day effect: p<0.01;* Table 16 and Figure 36). Following an initial improvement in error identification, performance also deteriorated towards the end of the shift (*Time effect: p<0.05:* Figure 37). In addition to this, while performance in the *Rolling rotation* and *Nap late conditions* remained relatively stable over time, reliability during the *Fixed night* condition improved initially and then decreased towards the end of the shift (*Condition by time: p<0.05:* Figure 37). Similarly, performance in the *Nap early* condition deteriorated following the nap (after test 2), before demonstrating some improvement. During the final two shifts, a similar decrement over time was observed (*Time effect: p<0.01*). A significant *condition by time* interaction demonstrated a similar trend as described above during the final two shifts (*p<0.05*).

Table 16: Statistical effects for error identification (high resolution object recognition test) during the night shift work period. * = p<0.05. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p=0.03*	ns	ns	p=0.01*	p<0.01*	p<0.01*	ns
Final	ns	p=0.03*	ns	ns	p<0.01*	ns	p=0.02*	ns

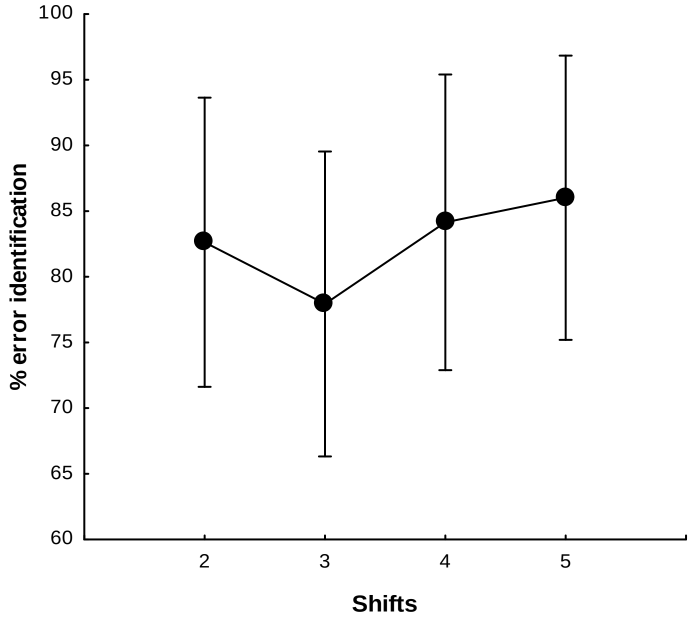

Figure 36: Reliability of errors identified (high resolution object recognition test) as a function of the four night shifts. Error bars denote a 95% confidence interval.

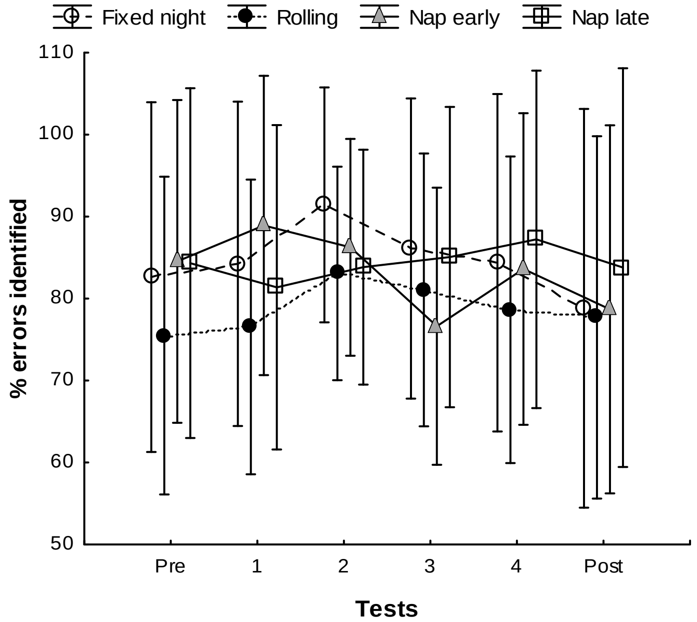

Figure 37: Reliability of errors identified (high resolution object recognition test) over the work shift. Graph shows responses for all conditions, for the four night shifts over time. Error bars denote a 95% confidence interval.

4.1.3.2.11 Simple reaction time (SRT)

This test reflected a *time of day* effect in that reaction time increased significantly over each shift generally and during the final two shifts (*Time effect: p<0.01:* Table 17 and Figure 38). Slowest reaction times coincided with tests three and four, with reaction time improving during the post shift test. In spite of this effect, SRT did not differ between the four conditions and did not significantly differ as a function of the four night shifts (Table 17). No other main or interaction effects were found.

Table 17: Statistical effects for simple reaction time during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	p<0.01*	ns	ns	ns
Final	ns	ns	ns	ns	p<0.01*	p=0.09#	ns	ns

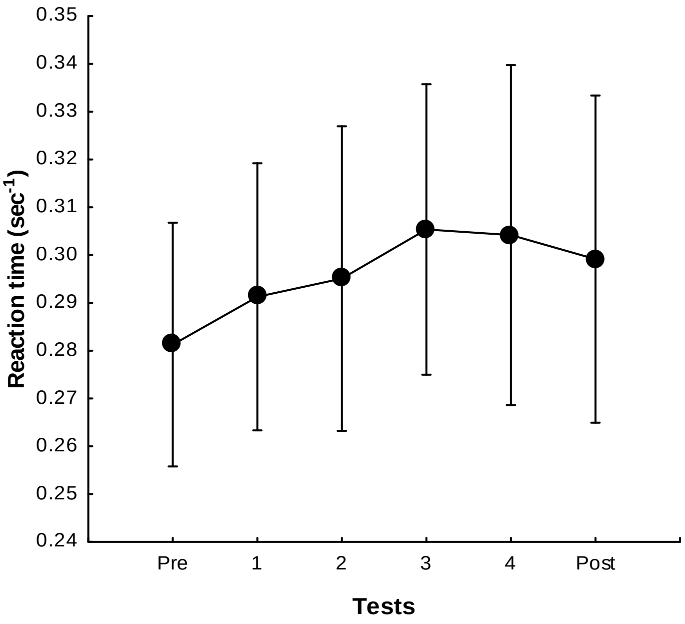

Figure 38: Reaction time over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.3 Cognitive measures

4.1.3.3.1 Working memory test (Long recall delay): percentage correctly recalled

A significant general effect of *condition* was identified (*p<0.05*) and post hoc tests revealed a significant difference between the *Fixed night* and *Nap late* conditions specifically (Table 18 and Figure 39). The *Rolling rotation* and *Nap early* conditions also performed better than *Nap late*, but this observation did not reach statistical significance (Figure 39). There were no other statistically significant effects. During the final two night shifts however, working memory performance in the *Fixed night* was better than *Nap late* group once again, while the percentage recalled also decreased significantly over the shift (*Time effect: p<0.01:* Table 18 and Figure 40).

Table 18: Statistical effects for percentage recalled (working memory test: long recall delay) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	p=0.02*	ns	ns	ns	p=0.07#	ns	ns	ns
Final	p=0.04*	ns	ns	ns	p<0.01*	ns	ns	ns

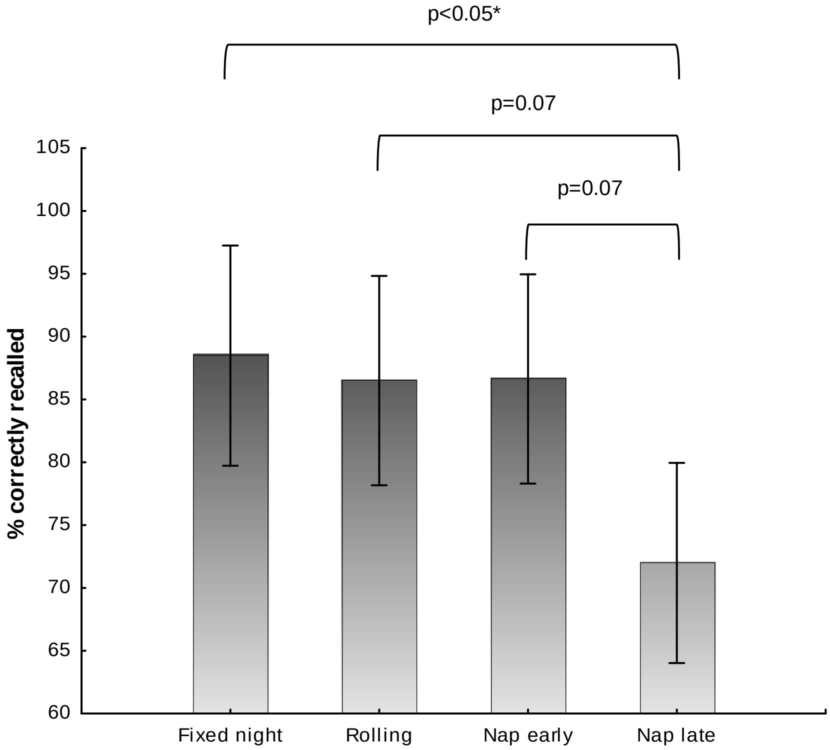

Figure 39: Percentage recalled (working memory test with long recall delay) for all conditions during the four night shifts. Brackets denote a significant difference between conditions Error bars denote a 95% confidence interval.

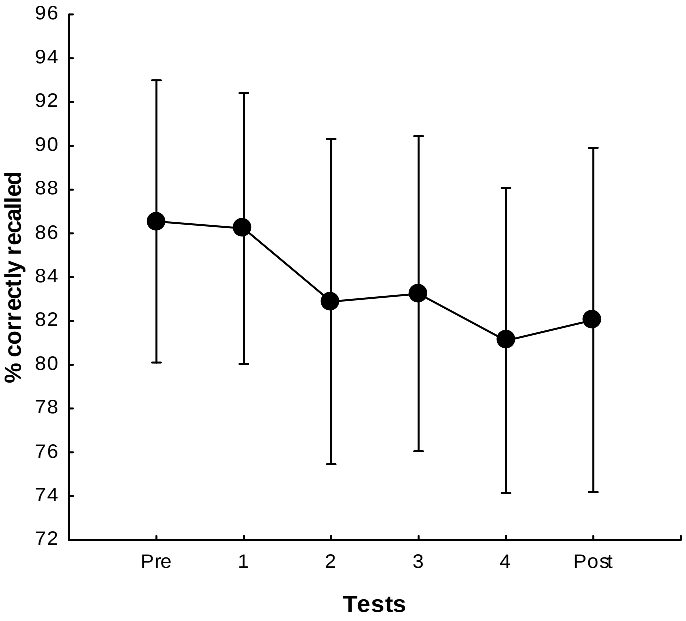

Figure 40: Percentage recalled (working memory test with long recall delay) over the work shift. Graph shows responses for the last two shifts over time. Error bars denote a 95% confidence interval.

4.1.3.3.2 Working memory test (short recall delay): percentage correctly recalled

In contrast to the complex version of this task, the general condition effect (*p<0.05*) and subsequent post hoc tests showed that the percentage recalled was significantly lower in the *Nap late* condition relative to *Nap early* condition (Table 19 and Figure 41). As with the more difficult version, both the *Rolling rotation* and the *Fixed night* groups also performed better than the *Nap late* condition, but this was not supported statistically (Figure 41). Further, performance improved over the four shifts (*Day effect*: *p<0.01:* Figure 42). During the final two shifts specifically, there was also a general condition effect (*p<0.05*), in that the *Fixed night* condition recalled significantly more numbers than the *Nap late* group, identified following post hoc analyses. The percentage recalled further improved from the penultimate to the last shift (*Day effect: p<0.05*), but still demonstrated the effects of fatigue, decreasing over time (*Time effect: p<0.05*: Table 19 and Figure 43).

Table 19: Statistical effects for percentage recalled (working memory test: short recall delay) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	p=0.02*	ns	ns	ns	p=0.09#	p<0.01*	ns	ns
Final	p=0.03*	ns	ns	ns	p=0.02*	p=0.02*	p=0.02*	ns

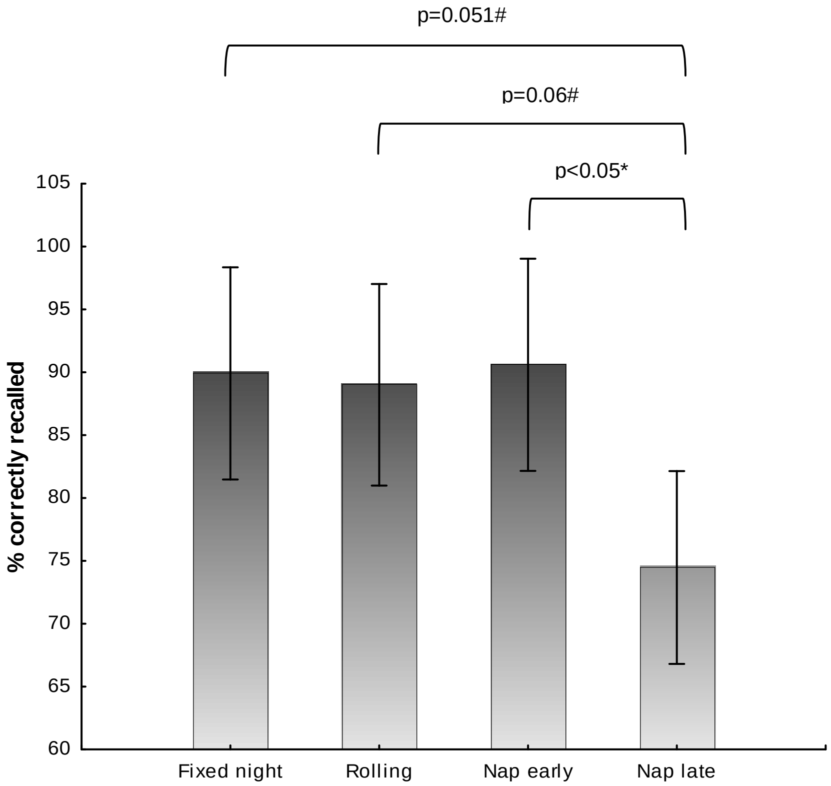

Figure 41: Percentage recalled (working memory test with short recall delay) for all conditions during the four night shifts. Brackets denote a significant difference between conditions. Error bars denote a 95% confidence interval.

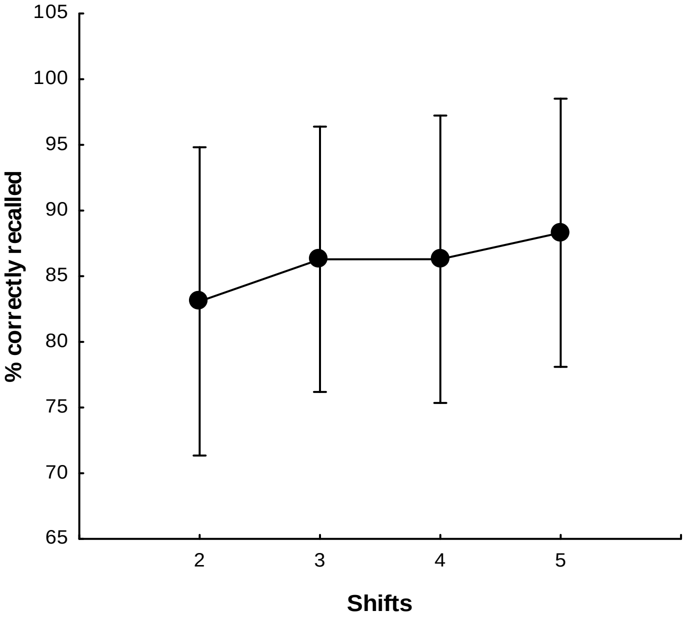

Figure 42: Percentage recalled (working memory test with short recall delay) as a function of the four night shifts. Error bars denote a 95% confidence interval.

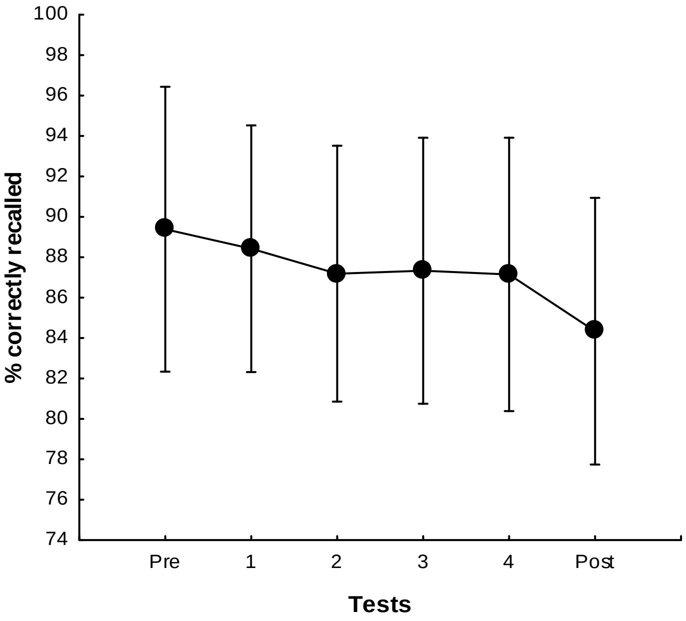

Figure 43: Percentage recalled (working memory test with short recall delay) over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.4 Psychomotor measures

4.1.3.4.1 Tapping test: Motor programming time

Motor programming time, which refers to the difference between the predictable and unpredictable stimuli presented during the tapping test, did not reflect any significant effects of the conditions (Table 20). Response time did however significantly increase over the course of the four shifts, plateauing during the last two (*Day effect*: *p<0.01:* Figure 44) while also reflecting time of day effects by increasing over each work shift (*Time effect: p<0.01*: Figure 45). There were no further main or interaction effects and only a significant time effect was found following the analyses of the final two shifts (*p<0.01*), where motor programming time increase over time.

Table 20: Statistical effects for motor programming time (tapping test) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	ns	ns	ns	p<0.01*	p<0.01*	p=0.051#	ns
Final	ns	ns	ns	ns	p<0.01*	ns	ns	ns

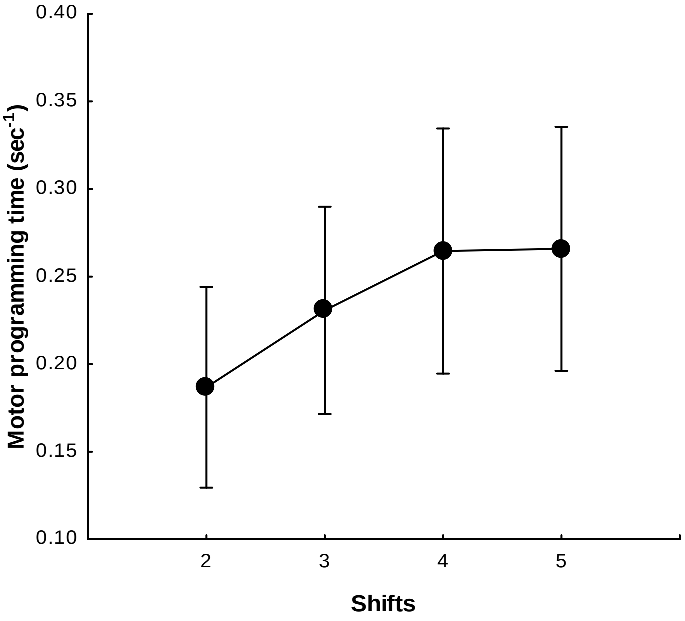

Figure 44: Motor programming time (tapping test) as a function of the four night shifts. Error bars denote a 95% confidence interval.

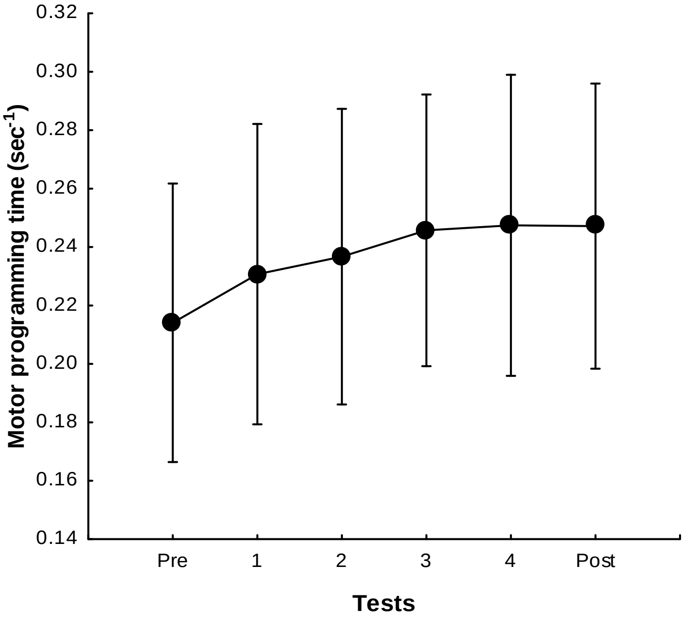

Figure 45: Motor programming time (tapping test) over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.4.2 Tapping test: High precision (small target) response time

Response time for this test did not differ between conditions or over the shift cycle (Table 21). Response time did reflect a time of day effect, increasing (slowed response time) during the first four tests and decreasing (faster response times) during the final two tests (*Time effect: p<0.01*: Figure 46). There were no other significant effects with this being the case following the analysis of the final two shifts.

Table 21: Statistical effects for high precision response time (tapping test) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p=0.07#	ns	ns	p<0.01*	ns	ns	ns
Final	ns	ns	ns	ns	ns	ns	ns	ns

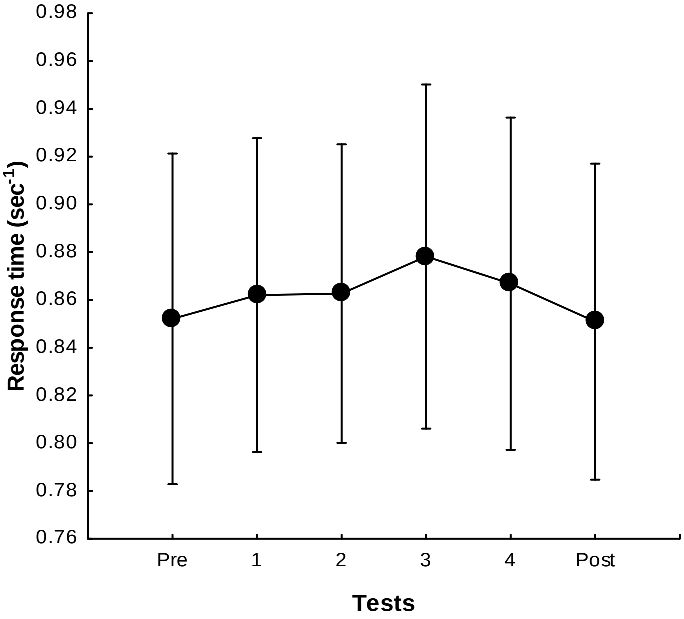

Figure 46: Response time for high precision targets (tapping test) over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.4.3 Tapping test: Low precision (large targets) response time

During this component of the tapping test (larger targets appearing at unpredictable places on the screen), there were also no significant effects of condition, day or time of day (Table 22). In addition, there were no significant interaction effects. This was the case following the analyses of the final two shifts as well.

Table 22: Statistical effects for low precision response time (tapping test) during the night shift work period. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p=0.054#	ns	ns	p=0.08#	ns	ns	ns
Final	ns	ns	ns	p=0.09#	ns	ns	ns	ns

4.1.3.4.4 Continuous tracking test (high sensitivity): reaction time

Tracking performance (motor control), denoted by reaction time of the frequency and amplitude of deviation from the tracking line, did not reflect any effects of the conditions and time of day (Table 23). However, reaction time did significantly improve (decrease) over the course of the four night shifts (*Day effect: $p<0.01$*: Figure 47). There were no other significant interaction effects, with the analysis of the final two shifts revealing no significant main or interaction effects either (Table 23).

Table 23: Statistical effects for reaction time (continuous tracking test: high sensitivity) during the night shift work period. * = $p<0.05$. ns = non-significant result ($p>0.1$).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	ns	ns	ns	ns	p<0.01*	ns	ns
Final	ns	ns	ns	ns	ns	ns	ns	ns

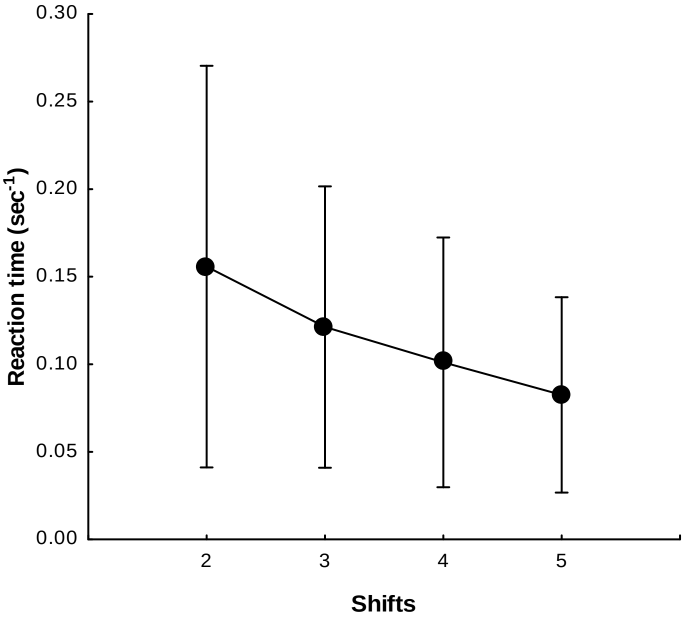

Figure 47: Reaction time (continuous tracking test with high sensitivity) as a function of the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.4.5 Continuous tracking test (low sensitivity): reaction time

Reaction time during the easier tracking task was not differentially affected by the conditions or time of day effects (Table 24). However, reaction time decreased over the course of the four night shifts (*Day effect: $p<0.01$*: Figure 48). A significant *time by day* interaction supported the observation that the worst performance occurred during the first night shift, specifically during the penultimate test (*$p<0.05$*). Thereafter, reaction time was significantly lower and more consistent across the tests. During the final two shifts, there were no significant effects of condition, time or day, but there was a three-way interaction between condition, time and day (*$p<0.05$*). With reference to Figure 49, reaction time was relatively stable for both *Rolling rotation* and *Nap late* conditions, while it fluctuated in the *Fixed night* and *Nap early* conditions. The time by day interaction supported the observation that performance during the penultimate shift was worse during the latter half the shift, while during the final shift, it was worse during the initial parts of the shift before it improved (Table 24 and Figure 49).

Table 24: Statistical effects for reaction time (continuous tracking task: low sensitivity) during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	ns	p<0.01*	p=0.01*	p=#0.06
Final	ns	ns	ns	p=0.03*	ns	p=0.09#	p<0.01*	p=#0.07

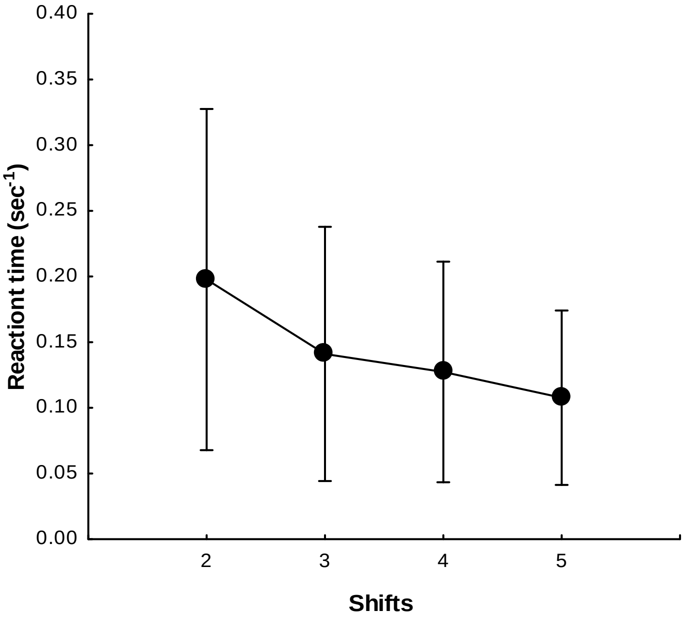

Figure 48: Reaction time (continuous tracking test with low sensitivity) as a function of the four night shifts. Error bars denote a 95% confidence interval.

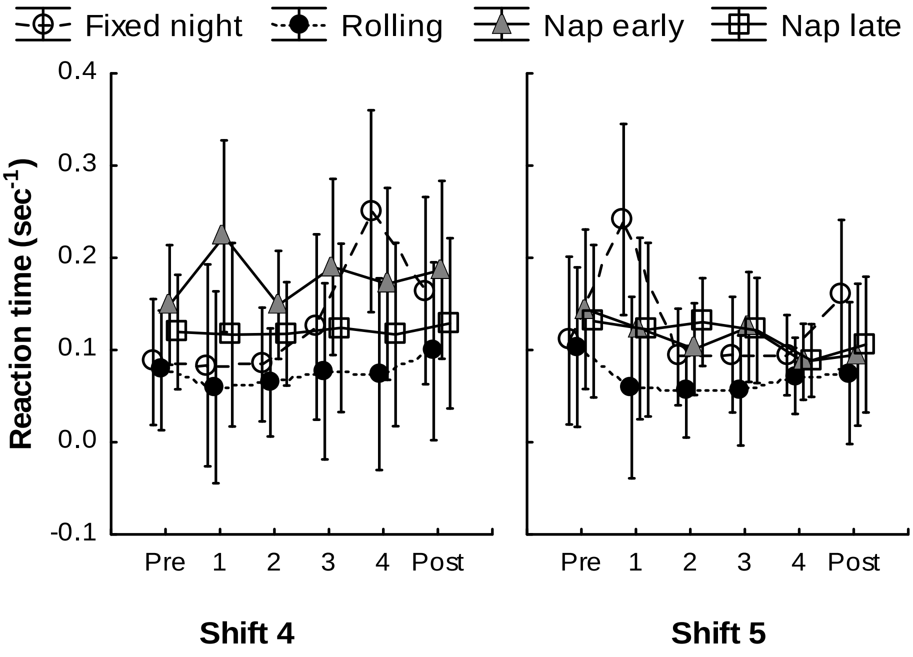

Figure 49: Reaction time (continuous tracking test with low sensitivity) for all conditions during the last two shifts. Error bars denote a 95% confidence interval.

4.1.3.5 Physiological measures

4.1.3.5.1 Tympanic temperature

Tympanic temperature responses did not differ between the four experimental conditions or over the four shifts analysed (Table 25). Temperature measures did however generally decrease over the course of each shift (*Time effect: p<0.01:* Figure 51). Responses also differed by condition over the four shifts in that they increased for *Nap late* group during the third night shift and remained higher than the initial two shifts (*Condition by day: p<0.05:* Table 25 and Figure 50). All other conditions displayed relatively consistent temperature responses during the four night shifts.

Tympanic temperature also differed over time by condition: responses were lower following both naps (relative to pre nap measures), and fluctuated in *Nap early* condition after this time, while increasing following the nap in *Nap late* group (*Condition by time effect*: *p<0.01:* Figure 51*)*. With respect to the *Fixed night* and *Rolling rotation* conditions, temperature measures continued to decrease, reaching a minimum towards the end of the shift. There was a three way interaction effect, illustrated in Figure 52, but no real pattern emerged. Female participants also displayed higher temperature measures relative to their male counterparts (*Sex effect: p<0.05*).

Table 25: Statistical effects for tympanic temperature during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p<0.01*	p=0.02*	p=0.02*	p<0.01*	ns	p=0.051#	p=0.02*
Final	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	p=0.05*

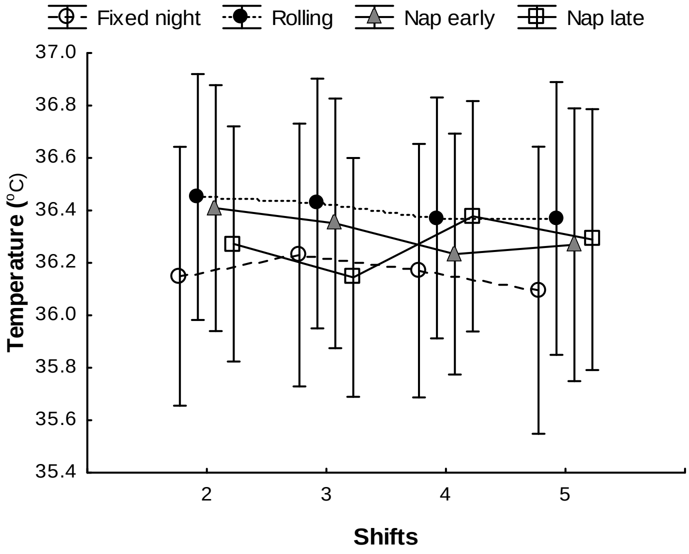

Figure 50: Tympanic temperature responses for all conditions as a function of the four night shifts. Error bars denote a 95% confidence interval.

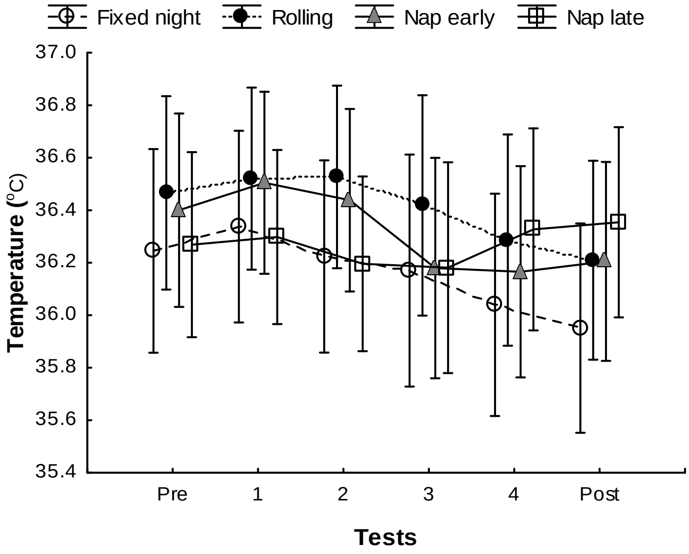

Figure 51: Temperature responses for all conditions over the work shift. Graph shows responses for all conditions over all four shifts. Error bars denote 95% confidence interval.

During the final two shifts, temperature measures did not differ between the conditions or between the two days. Responses decreased significantly over time (*p<0.01*) and there was a significant *condition by time* interaction (*p<0.01*: Table 25) that resembled the general effect over all four shifts.

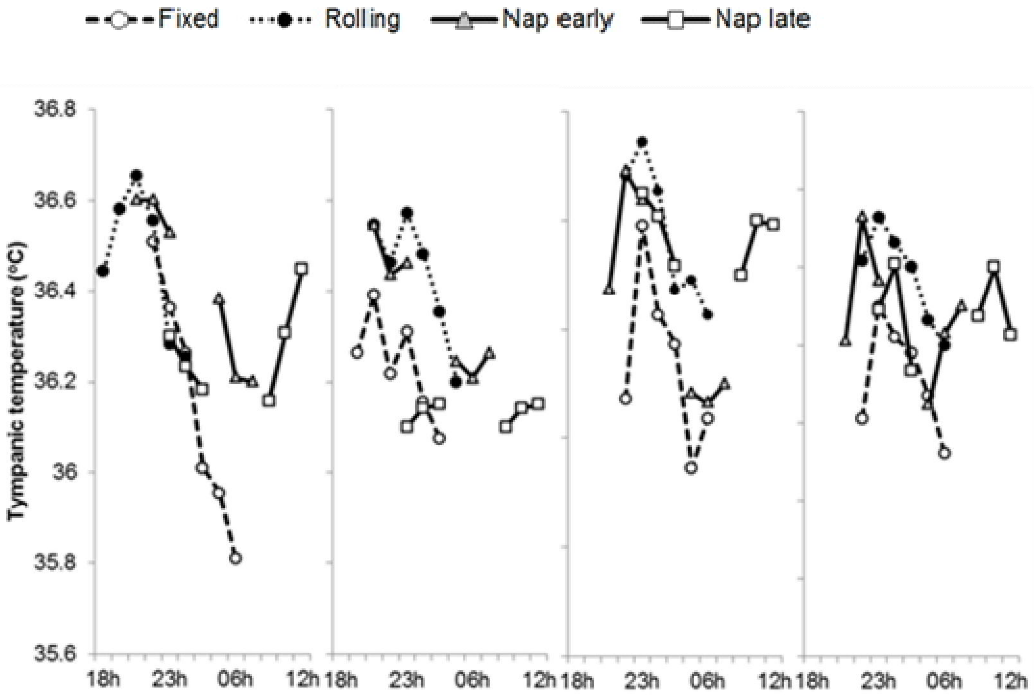

Figure 52: Tympanic temperature responses during the four night shifts. Shifts progress from left to right.

4.1.3.5.2 Heart rate frequency (HRF) and heart rate variability (HRV)

Cardiovascular responses were monitored throughout each shift, with belts only being removed when the *Nap early* and *Nap late* condition participants went to nap. During data reduction, all HRF and HRV information was split into responses obtained during testing and those obtained during the work periods. These intervals, of which there were ten (five testing periods and five work periods) were analysed separately. Only data from the last three shifts was analysed as a significant portion of data from the *Nap early* group was lost due to equipment malfunction during the first night shift.

4.1.3.5.3 Heart rate frequency (HRF)

Measures during the test batteries

HRF during the test batteries did not differ between the four conditions, nor did it change over the three shifts that were analysed. It did however decrease significantly over time (*Time effect: p<0.01:* Table 26 and Figure 53, top panel). Additionally, there was a significant *condition by time* interaction: HRF responses decreased significantly over time in both the *Fixed nap* and *Rolling rotation* conditions (*p<0.01*: Table 26 and Figure 53, top panel). In contrast, responses were higher following the nap in both the *Nap early* and *Nap late* groups. Post hoc tests revealed HRF was only significantly higher in the *Nap late* condition following the nap. Measures were also significantly higher in females compared to males (*Sex effect: p<0.01*: Table 26). With respect to the final two shifts, there were no general differences between the conditions. Sex did elicit an effect in that females expressed higher responses (*p<0.01*), and a significant interaction effect (*Condition and time effect: p<0.01*) similar to the general effect described previously, was found. No other effects were noted.

Table 26: Statistical effects for heart rate frequency for the test batteries during the night shift work period. * = p<0.05. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	p<0.01*
Final	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	p<0.01*

Measures during the work periods

During the work periods, heart rate frequency also decreased significantly over time, with this change being dependent upon the effects of the conditions (*Condition by time interaction: p<0.01*: Table 27; Figure 53, bottom panel). The responses were similar to that which was described in the responses analysed during test batteries.

Table 27: Statistical effects for heart rate frequency for the work periods during the night shift work period. * = p<0.01. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	p<0.01*
Final	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	p<0.01*

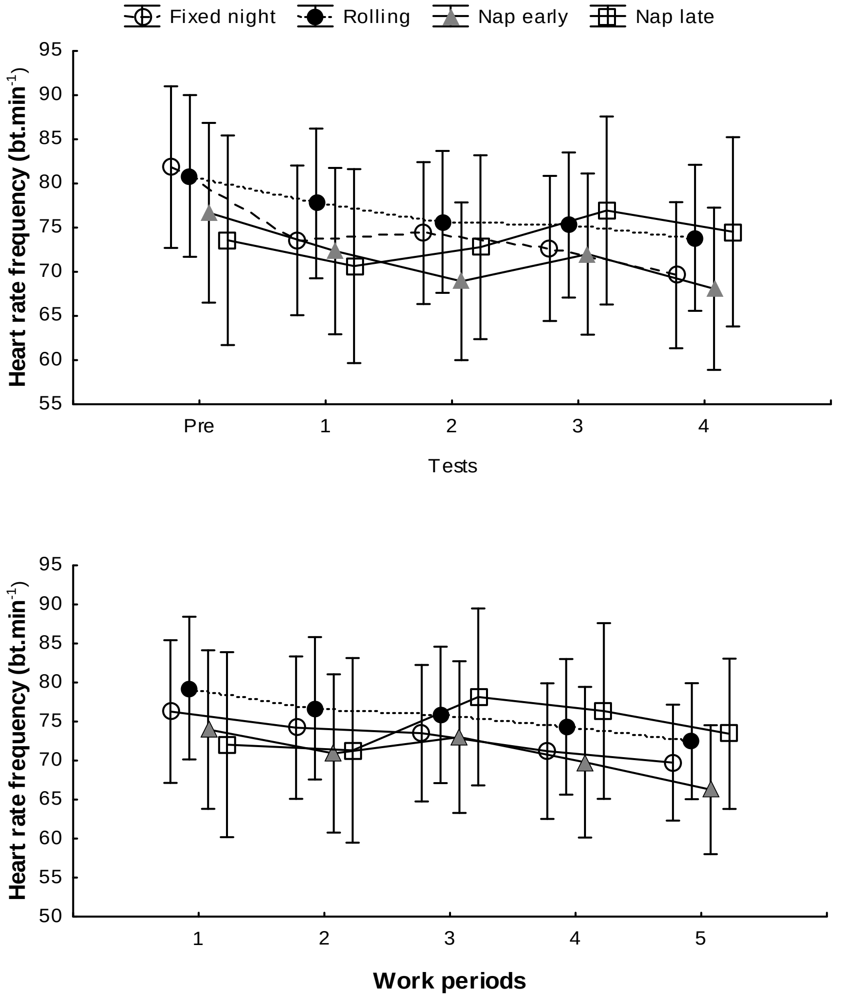

Figure 53: Heart rate frequency during test batteries (top panel) and work periods (bottom panel) for all conditions over the work shift. Graph shows responses for all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.5.4 Heart rate variability: Time domain analysis

Measures during the test batteries

r-MSSD was used as a time domain measure of HRV. The conditions did not elicit any differential effects on r-MSSD responses, which also remained stable over the three shifts that were analysed (Table 28). However, r-MSSD increased significantly over time (*Time effect: p<0.01*: Figure 54, top panel). The nature of this increase was altered significantly by some of the conditions: responses decreased after the nap in the *Nap late* condition, relative to the responses in the *Rolling rotation*, *Fixed night* and *Nap early* conditions (*Condition by time effect: p<0.01*: Figure 54, top panel).

After this initial decrease however, responses increased consistently towards the end of the shift. A comparison of the final two shifts revealed a time effect ($p<0.01$), which was modified by the different conditions ($p<0.01$; as discussed above). No other significant effects were noted (Table 28).

Table 28: Statistical effects for r-MSSD for the test batteries during the night shift work period. * = p<0.01. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	ns
Final	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	ns

Measures during the work periods

In a similar manner to responses observed during the test batteries, r-MSSD measures during the work periods did not differ significantly between conditions or over the three night shifts. However, responses generally increased significantly over time (*Time effect:* $p<0.05$: Table 29; Figure 54, bottom panel), with this change being dependent upon condition (*Condition by time interaction:* $p<0.01$; Figure 54, bottom panel). Specifically, while r-MSSD increased in both the *Fixed night* and *Rolling rotation* conditions over the work periods, responses in both Nap groups decreased over the initial two work periods, before increasing towards the end of the shift. During the final two shifts, r-MSSD increased generally over time (*Time effect;* $p<0.05$; Table 29), with this change being mediated by the condition (*Condition by time interaction;* $p<0.01$). The trend of this change was similar to that of the main effect.

Table 29: Statistical effects for r-MSSD for the work periods during the night shift work period. * = p<0.01. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
General	ns	p<0.01*	ns	ns	p<0.05*	ns	p<0.05*	ns
Final	ns	p<0.05*	ns	ns	p<0.01*	ns	ns	ns

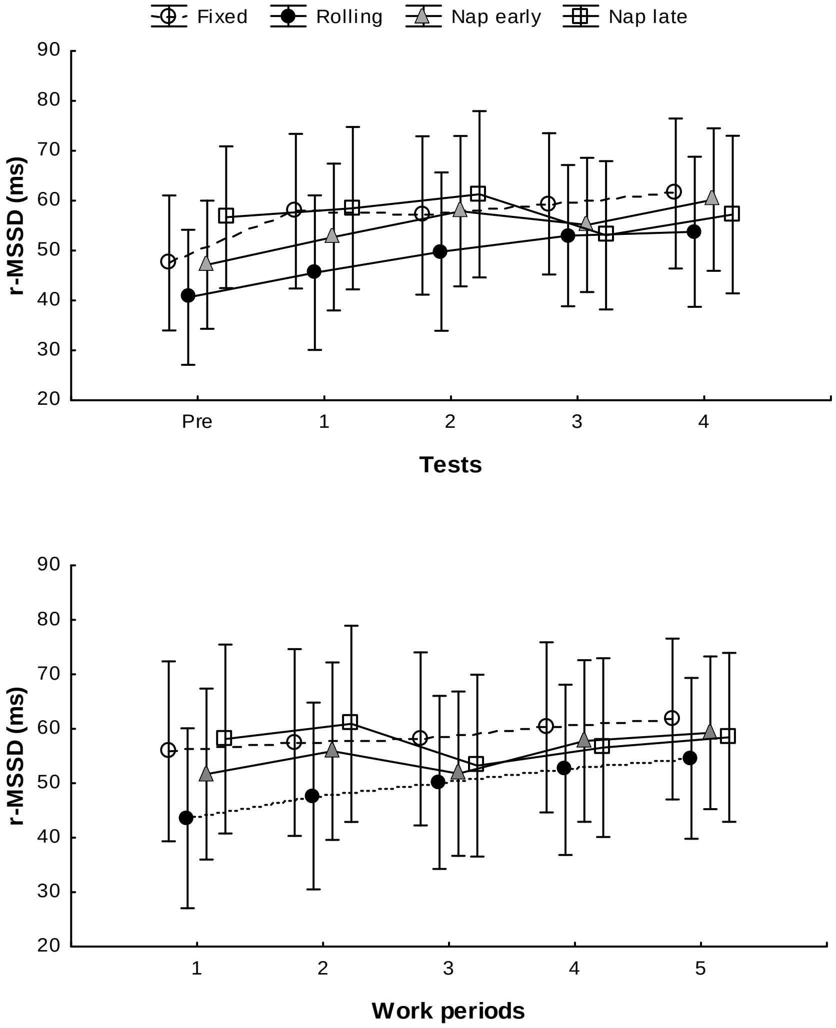

Figure 54: r-MSSD responses for both test batteries (top panel) and work (bottom panel) intervals for all conditions over the work shift. Graph shows responses over all four shifts over time. Error bars denote a 95% confidence interval.

4.1.3.5.5 Frequency domain analysis: Normalised low frequency power (LF nu)

Measures during the test batteries

LF nu did not differ between the conditions, over time or over the course of the three shifts. There were no significant interaction effects noted either (Table 30). Similarly, during the final two shifts, there were no general differences between the conditions and responses did not change significantly over time or the four night shifts. However, there was a significant *Condition by time* interaction (*p<0.01*: Table 30): as illustrated in Figure 55, while LF nu were relatively stable in the *Fixed night, Rolling rotation* and the *Nap late* conditions, normalised LF power increased in the *Nap early* group over the course of the shift, most notably after the nap (which occurred between tests two and three. There were no other significant effects.

Table 30: Statistical effects for LFnu for the test batteries during the night shift work period. p<0.01*. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	ns	ns	ns	ns	ns	ns	ns
Final	ns	p<0.01*	ns	ns	ns	ns	ns	ns

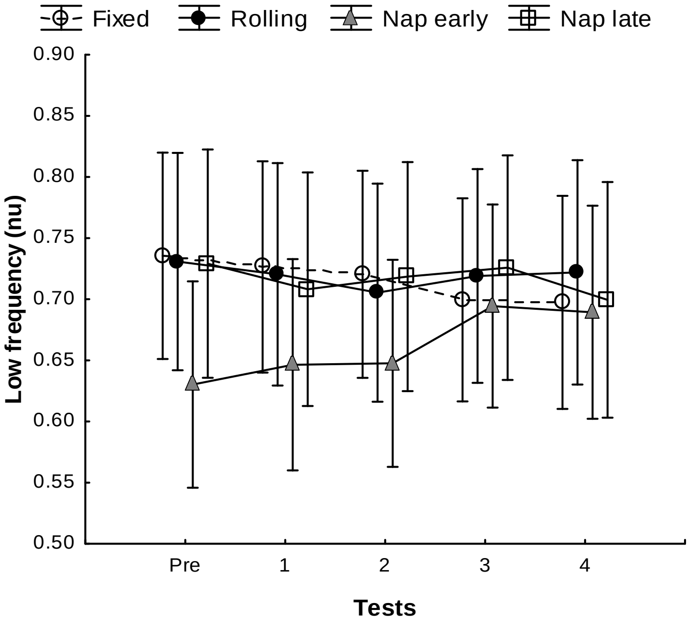

Figure 55: Normalised low frequency power responses for all conditions during the test batteries over the work shift. Graph shows responses over the last two shifts. Error bars denote confidence interval of 95%.

Measures during the work periods

Similar to the responses during the test batteries, LF nu did not differ between the conditions, over time or over the three night shifts. However responses over time were dependent upon condition (*Condition by time interaction: p<0.01*; Table 31). More specifically, LF nu increased in the *Nap early* group over time, while remaining relatively stable for the other conditions. Additionally, there was a decrease in responses in the *Nap late* condition between test three and test four (Figure 56). During the final two shifts, there were no significant effects other than a *Condition by time* interaction (*p<0.01*) the trend for which was similar to the general effect described above.

Table 31: Statistical effects for LFnu for the work periods during the night shift work period. $p<0.01$*. # = $p<0.1$. ns = non-significant result ($p>0.1$).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	ns	p<0.05*	ns	ns	ns	ns	ns	ns
Final	ns	p<0.01*	ns	ns	ns	ns	ns	ns

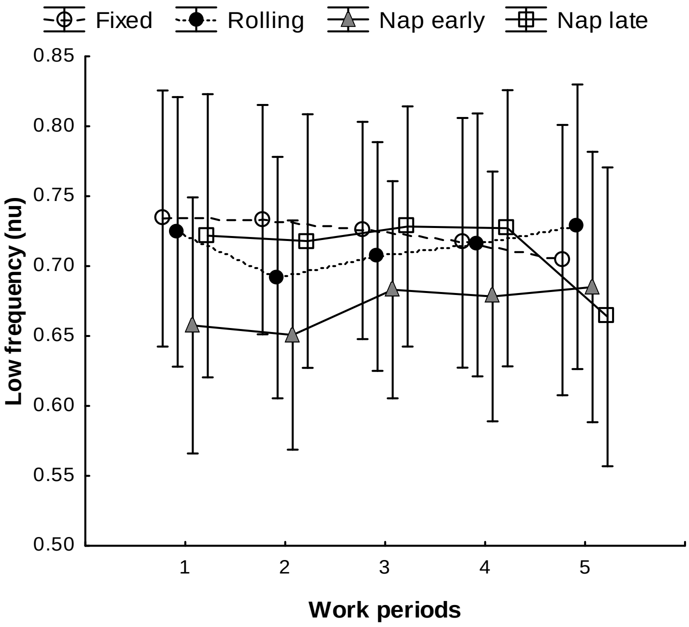

Figure 56: Normalised low frequency power responses for all conditions during the work periods over the work shift. Graph shows responses over the last three shifts. Error bars denote a 95%confidence interval.

4.1.3.6 Subjective measures

4.1.3.6.1 Karolinska Sleepiness scale: subjective sleepiness

Subjective ratings of sleepiness did not differ generally between the conditions (Table 32), but ratings were lower in the *Nap late (p=0.051)*, *Nap early* and *Rolling rotation* conditions (Figure 57). Sleepiness did not differ significantly over the four days (Table 32), but did increase significantly during each shift (*Time effect: p<0.01*: Figure 58). This increase in sleepiness was also dependent upon the conditions in that following the completion of both naps in the *Nap early* and *Nap late* conditions, sleepiness was significantly reduced as compared to the ratings in the *Rolling rotation* and *Fixed night* condition (*Condition by time effect*: *p<0.05:* Figure 58).

Table 32: Statistical effects for subjective sleepiness during the night shift work period. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
General	p=0.07#	p<0.01*	p<0.01*	ns	p<0.01*	ns	p<0.01*	ns
Final	ns	p<0.01*	ns	ns	p<0.01*	ns	ns	ns

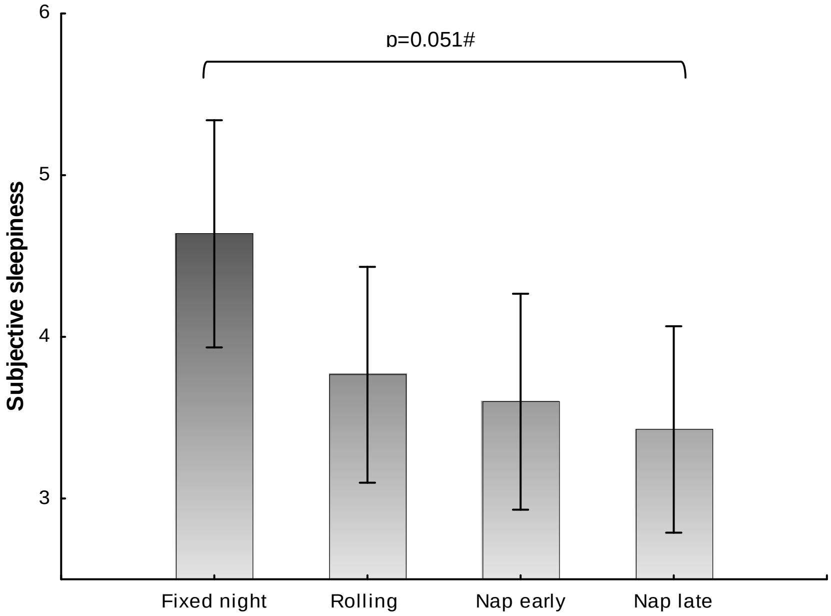

Figure 57: Subjective sleepiness measures for all condition during the four night shifts . Error bars denote a 95% confidence interval.

Additionally, there was a significant *condition by day interaction* (*p<0.01*): with reference to Figure 59 this referred mostly to how sleepiness ratings remained relatively similar for the *Fixed night, Nap early* and *Nap late* conditions over the four night shifts, but significantly increased in the *Rolling rotation* condition as this group entered the same shift times as the *Fixed night* group (which occurred at Shift 4). There were no other significant effects.

During the final two nights, responses increased under the effects of time of day (*p<0.01*), with the naps in both the *Nap early* and *Nap late* conditions significantly reducing this increasing sleepiness, relative to the other two conditions (*Condition by time effect: p<0.01*: Table 32).

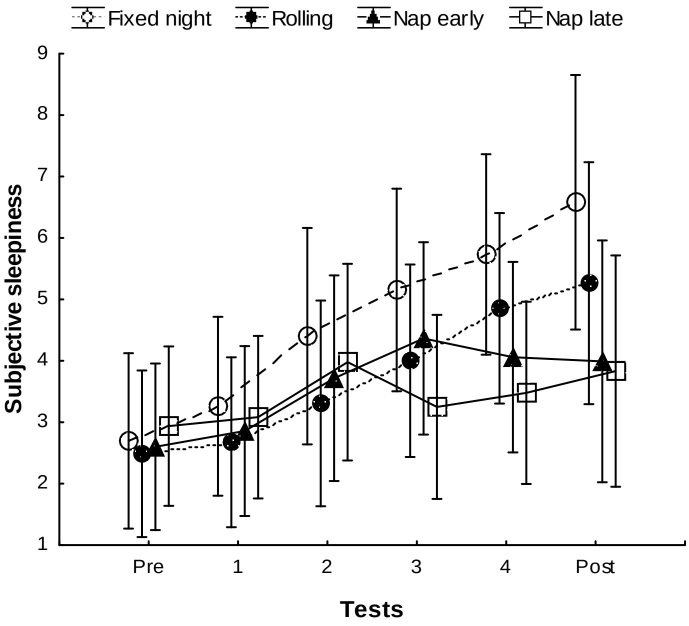

Figure 58: Subjective sleepiness for all conditions over the work shift. Graph show responses over all four work shifts. Error bars denote a 95% confidence interval.

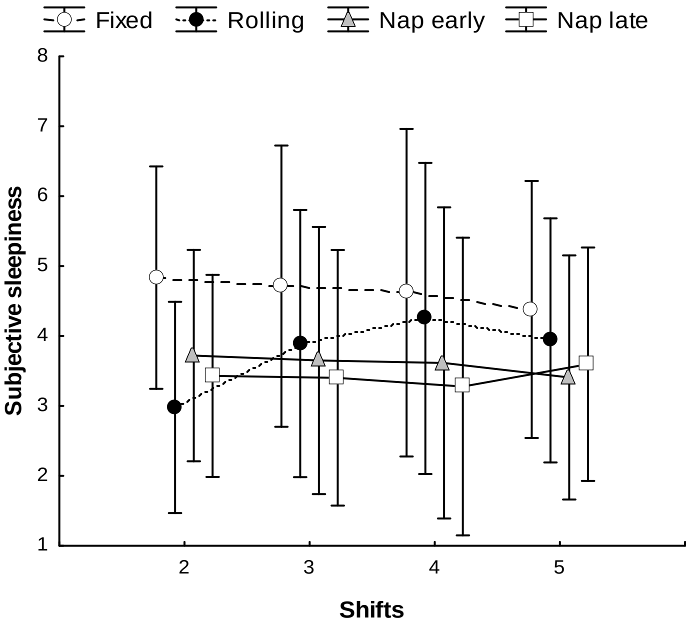

Figure 59: Subjective sleepiness for all conditions as a function of the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.7 Characteristics and effects of the naps

The following section will focus exclusively on presenting the specific effects associated with the two napping conditions. This refers to the perceived sleep length and quality during the nap opportunity.

4.1.3.7.1 Perceived sleep length during the nap opportunities

Perceived length of the sleep differed significantly between the two napping conditions (*Condition effect: p<0.01)*: the participants in the *Nap late* condition reported an average sleep length of 180.3 (±25.9) minutes which was longer than the *Nap early* group, who averaged 145.34 (±30.8) minutes. This amounted to an average difference of 34.9 minutes (Table 33 and Figure 60). Perceived sleep length did not differ significantly over the data collection period (*Day effect*), and there was no significant difference observed between the sexes.

Table 33: Statistical effects for perceived sleep length during the nap opportunity over the four night shifts. * = p<0.05. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**C*T*D**	**Time**	**Day**	**Time*Day**	**Sex**
P value	p<0.05*	-	ns	-		ns	-	ns

4.1.3.7.2 Perceived sleep quality during the nap opportunities

Participants in the *Nap late* condition reported better quality sleep during the napping opportunity when compared to those in the *Nap early* group (*p<0.05*: Table 34). Sleep quality ratings did not differ significantly over the four night shifts and no other interaction effects were found. There was however a significant difference between males and females (*p<0.05*): specifically, females reported better sleep quality than males during the napping opportunities.

Table 34: Statistical effects for perceived sleep quality during the nap opportunity over the four night shifts. * = p<0.05. ns = non-significant result (p>0.1).

	Condition	**Condition*Time**	**Condition*Day**	**Time**	**Day**	**Time*Day**	**Sex**
p value	p=0.02*	-	ns		ns	-	p= 0.05*

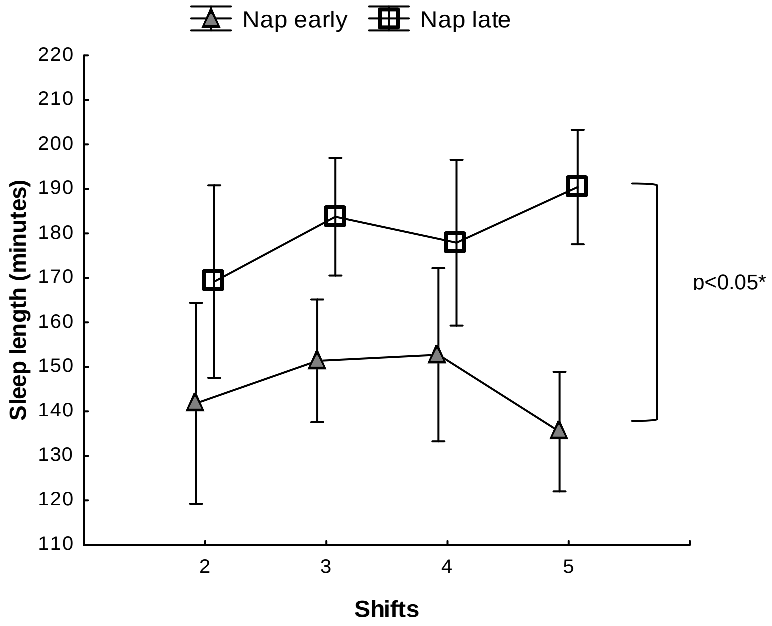

Figure 60: Perceived nap length (minutes) for the *Nap early* and *Nap late* conditions during the four night shifts. Bracket denotes a significant difference between conditions ($p<0.05$). Error bars denote a 95% confidence interval.

4.1.3.8 Sleep inertia effects

The presence of sleep inertia was determined by comparing the responses of all outcome measures during the pre-nap test to those during the post nap test in both napping conditions only. Main and interaction effects are reported on, with the time effect in this context referring to either the effects of sleep inertia (where performance / alertness is decreased after the nap) or recovery, where there is an improvement in responses. All other statistical effects correspond with those outlined in the Statistical considerations section (p108). The statistical effects for all measures are summarised in Table 35 below.

4.1.3.8.1 Choice reaction time

Choice reaction time was significantly slower during the post nap test, relative to the pre nap test (*Sleep inertia effect*: $p<0.01$: Table 35 and Figure 61), irrespective of condition. There were no other significant effects.

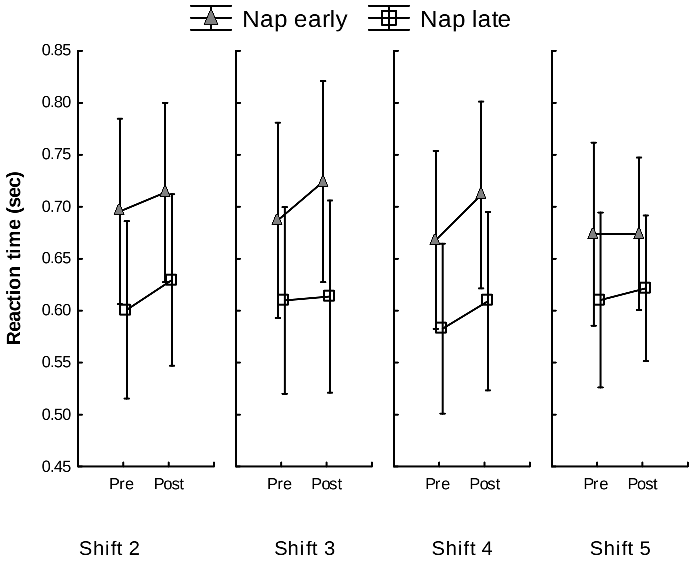

Figure 61: Choice reaction time measures before and after the nap for both nap conditions over the four night shifts. Errors bars denote a 95% confidence interval.

4.1.3.8.2 Percentage overlooked (error rate): Visual detection test with 80 distractors

Error rate was higher in the *Nap late* condition during the post nap test, relative to the pre nap test. In contrast, error rate decreased in the *Nap early* condition following the pre-post nap comparison (*Condition by time: p<0.05*: Table 35 and Figure 62). No other significant effects were found.

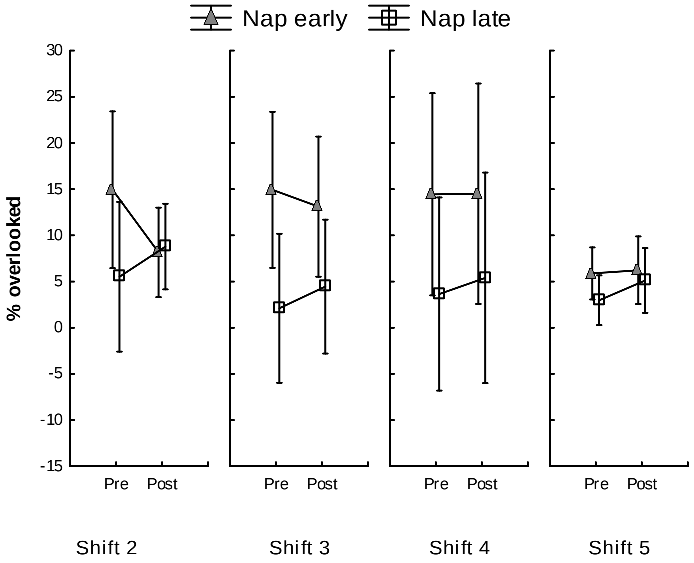

Figure 62: Percentage overlooked during the visual detection test (80) before and after the nap for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.3 Percentage overlooked (error rate): Visual detection test with 40 distractors

Error rate during the easier version of this test revealed a significant *Day effect* (*$p<0.05$;* Table 35 and Figure 63); error rate significantly decreased over the course of the four night shifts, irrespective of the conditions. There were no other statistically significant effects.

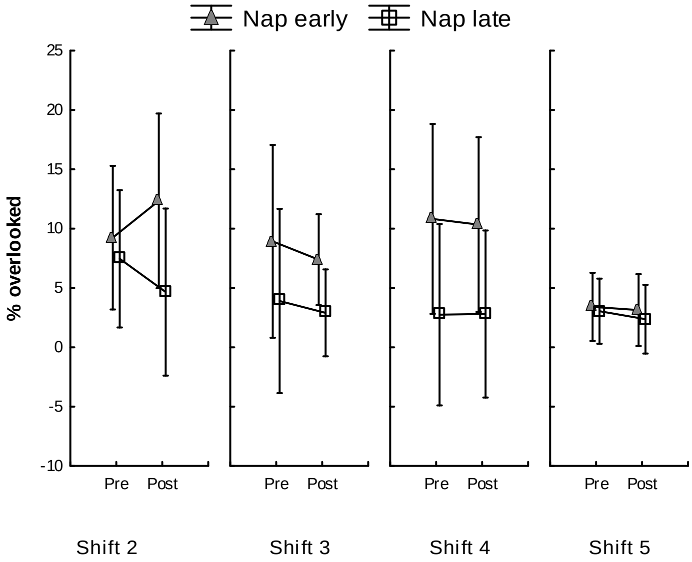

Figure 63: Percentage overlooked during the visual detection test (40) before and after the nap for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.4 Low resolution object recognition test: processing speed

Processing speed was significantly reduced in the post nap test when compared to the pre nap test (*Sleep inertia effect: $p<0.05$*; Table 35 and Figure 64). Additionally, there was a significant reduction in processing speed as a function of the four night shifts (*Day effect; $p<0.01$*: Figure 64). Furthermore, the change in responses over the four night shifts differed significantly between the two conditions: processing speed generally decreased in the *Nap early* condition over the four shifts, while it increased for the *Nap late* condition (*Condition by day effect: $p<0.05$*). No other significant effects were found.

Table 35: Pre-post nap test comparisons for all dependent variables to determine the presence of sleep inertia following the protected sleep period. * = p<0.05. # = p<0.1. NS = non-significant result (p>0.1).

Type of variable	**Dependent variable**	**Difficulty**	**Outcome measure**	**Condition effects** p value	**Sleep inertia (pre-post) effects** p value	**Day effects** p value	**Condition x time** p value	**Condition x day** p value	**Day x time** p value	**C x T x D** p value	**Sex** p value
Performance	**Beading task**	–	*Beading performance*	–	–	–	–	–	–	–	–
Visual perception measures	**Accommodation test**	–	*Accommodation time*	0.8	0.99	0.23	0.08	0.9	0.26	0.81	
		–	*Choice reaction time*	0.13	p<0.01*	0.61	0.62	0.64	0.3	0.39	0.98
	Visual detection test	80 distractors	*Median reaction time*	0.28	0.51	0.11	0.19	0.14	0.99	0.35	0.93
		40 distractors	*Median reaction time*	0.22	0.88	p=0.051#	0.85	0.47	0.67	0.54	0.43
		80 distractors	*% of stimuli overlooked*	0.12	0.86	0.15	p<0.05*	0.14	0.63	0.3	0.77
		40 distractors	*% of stimuli overlooked*	0.13	0.7	p<0.05*	0.58	0.21	0.97	0.68	0.98
	Objection recognition / reading test	Low resolution	*Processing speed*	0.55	p<0.05*	p<0.01*	0.32	p<0.05*	0.97	0.39	0.96
		High resolution	*Processing speed*	0.31	p<0.01*	0.48	0.72	0.44	0.8	0.91	0.76
		Low resolution	*% errors identified*	p<0.05*	0.68	p<0.01*	0.2	0.09#	0.93	0.45	0.35
		High resolution	*% errors identified*	p<0.05*	0.32	0.11	0.73	0.13	0.32	p<0.01*	0.11
	Simple reaction test	–	*Median reaction time*	0.31	p<0.05*	0.54	0.95	0.24	0.12	0.68	0.73
Cognitive measures	**Working memory digit span test**	Long delay	*% correctly recalled*	p<0.05*	0.92	0.45	0.23	0.48	0.23	0.11	0.25
		Short delay	*% correctly recalled*	p<0.05*	0.57	0.92	0.9	0.59	0.57	0.71	0.09#
Psychomotor measures	**Modified tapping test**	–	*Motor programming time*	0.32	0.71	p<0.01*	0.59	0.48	0.52	0.68	0.25
		–	*High precision Response time*	0.85	0.55	0.48	0.1	0.28	0.37	0.59	0.25
		–	*Low precision Response time*	0.71	0.65	0.94	p=0.051#	0.11	0.6	0.28	p<0.05*
	Continuous tracking test	High sensitivity	*Median reaction time*	0.25	0.62	0.71	0.5	0.54	0.56	0.46	0.3
		Low sensitivity	*Median reaction time*	0.4	0.36	0.45	0.31	0.39	0.53	0.39	0.23
Physiological	**Tympanic temperature**	–	*Body temperature*	0.39	p<0.01*	0.69	0.28	0.65	0.49	0.52	p<0.05*
	Heart rate frequency	–		0.08	p<0.01*	0.32	0.37	0.11	0.9	0.32	p<0.05*
	r-MSSD	–	*Time domain analysis*	0.61	p<0.01*	0.91	0.27	0.65	p<0.05*	0.72	0.07#
	Low frequency power (normalised)	–	*Frequency domain analysis*	0.17	0.98	0.97	0.99	0.37	0.64	0.72	0.84
Subjective	**Karolinska Sleepiness scale**	–	*Subjective sleepiness*	0.59	0.1	0.84	0.87	0.61	0.17	0.18	p<0.05*

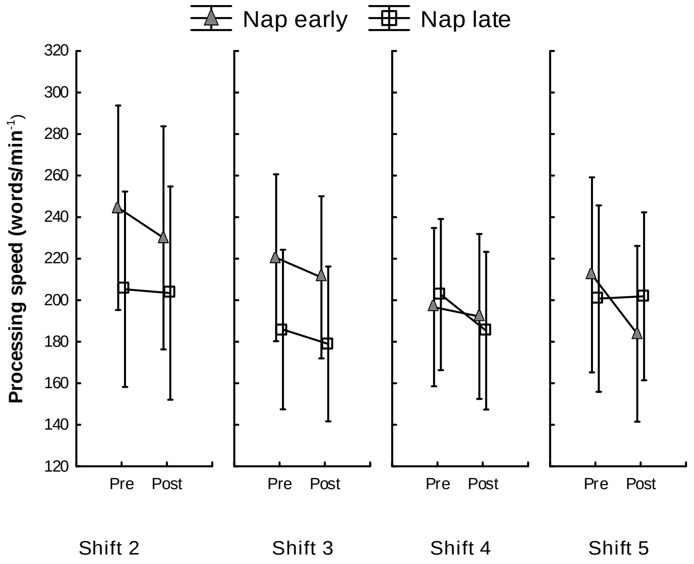

Figure 64: Processing speed during the low resolution object recognition tests before and after the nap for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.5 High resolution object recognition test: processing speed

As with the more difficult version of this task, processing speed was significantly reduced during the post nap test when compared to the pre nap test (*Sleep inertia effect: p<0.01*: Table 35 and Figure 65). There were no other statistically significant differences noted.

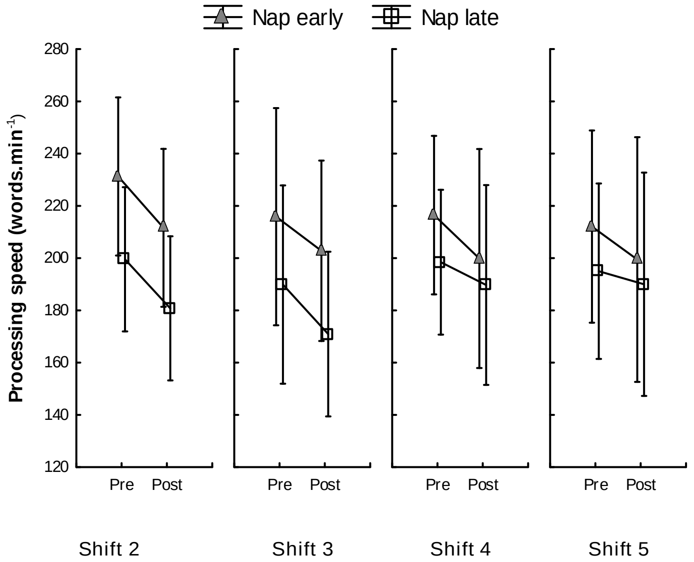

Figure 65: Processing speed during the high resolution object recognition test before and after the nap for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.6 Simple reaction time

Reaction time was significantly slower during the post nap test, relative to the pre nap test, irrespective of condition (*Sleep inertia effect: p<0.05*: Table 35 and Figure 66). Apart from this, there were no other statistically significant results.

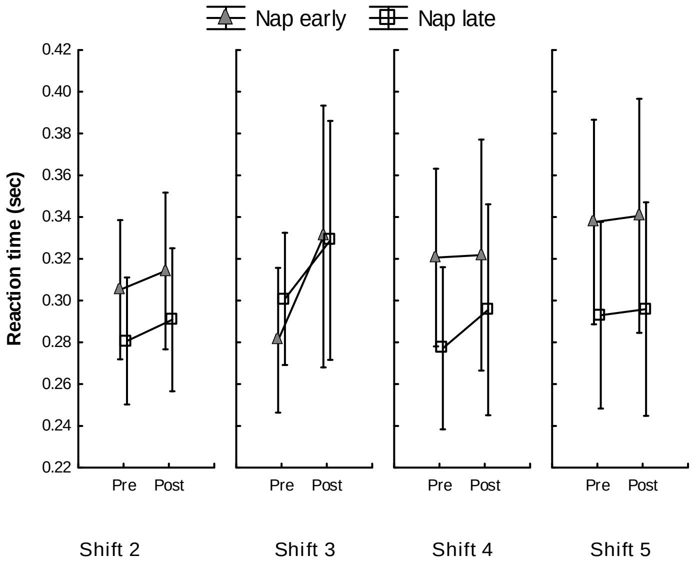

Figure 66: Simple reaction time measures before and after the naps for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.7 Low resolution object recognition test: errors identified/ reliability

Reliability during this test differed significantly between the conditions (*Condition effect: p<0.05*: Table 35 and Figure 67, top graphic). Specifically, the errors identified were significantly higher in the *Nap late* condition, when compared to the *Nap early* condition. In addition, the reliability significantly increased as a function of the four night shifts (*Day effect: p<0.01).*

4.1.3.8.8 High resolution object recognition task: errors identified

As with the more difficult version of this test, reliability differed significantly between conditions (*Condition effect: p<0.05*: Table 35 and Figure 67, bottom graphic*)* in that the *Nap late* condition identified more errors generally, when compared to the *Nap early* condition.

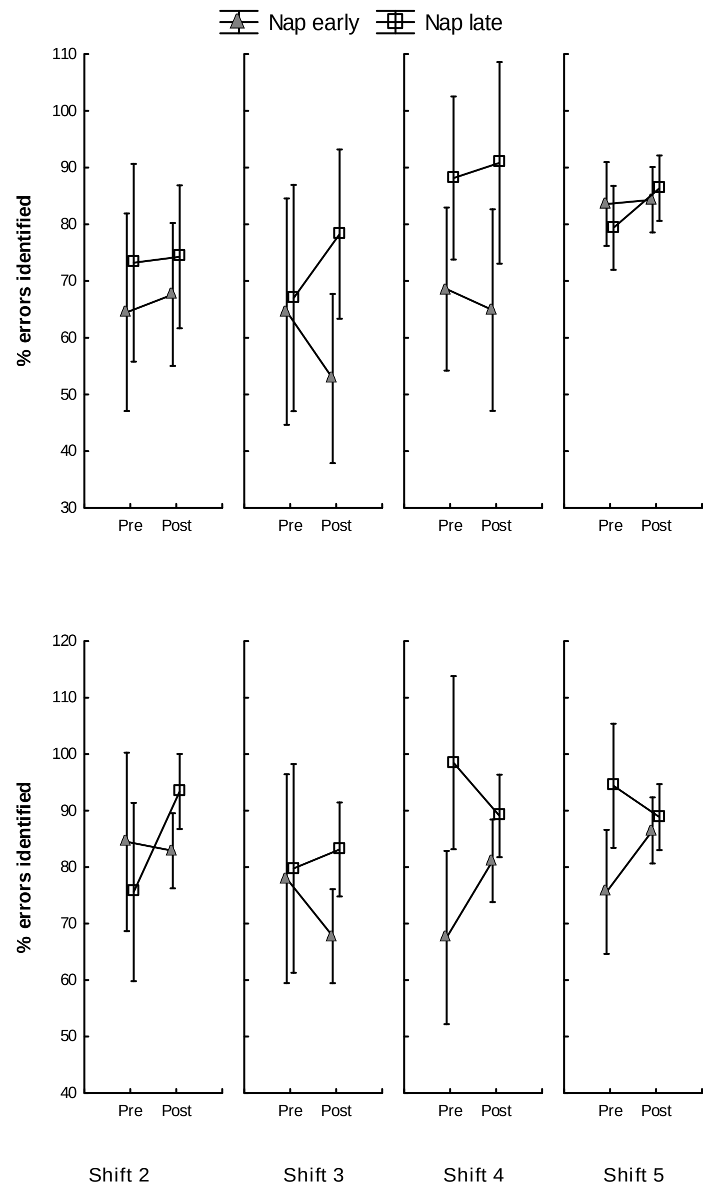

Figure 67: Errors identified during the low resolution (top panel) and high resolution (bottom panel) object recognition test before and after the nap for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.9 Working memory (long recall delay): percentage correctly recalled

During this test, the percentage recalled was significantly higher for the *Nap early* condition, relative to the *Nap late* condition, a result that was similar to the main condition effect referred to earlier in the results section (*Condition effect: p<0.05*: Table 35 and Figure 68, top graphic). There were no other significant effects.

4.1.3.8.10 Working memory (short recall delay): percentage correctly recalled

Similarly, the percentage of numbers recalled correctly was significantly higher in the *Nap early* group as compared to the *Nap late* condition (*Condition effect: p<0.05*; Table 35 and Figure 68, bottom graphic).

4.1.3.8.11 Motor programming time

During the tapping task, motor programming time significantly increased over the four night shifts (*Day effect: p<0.01*).

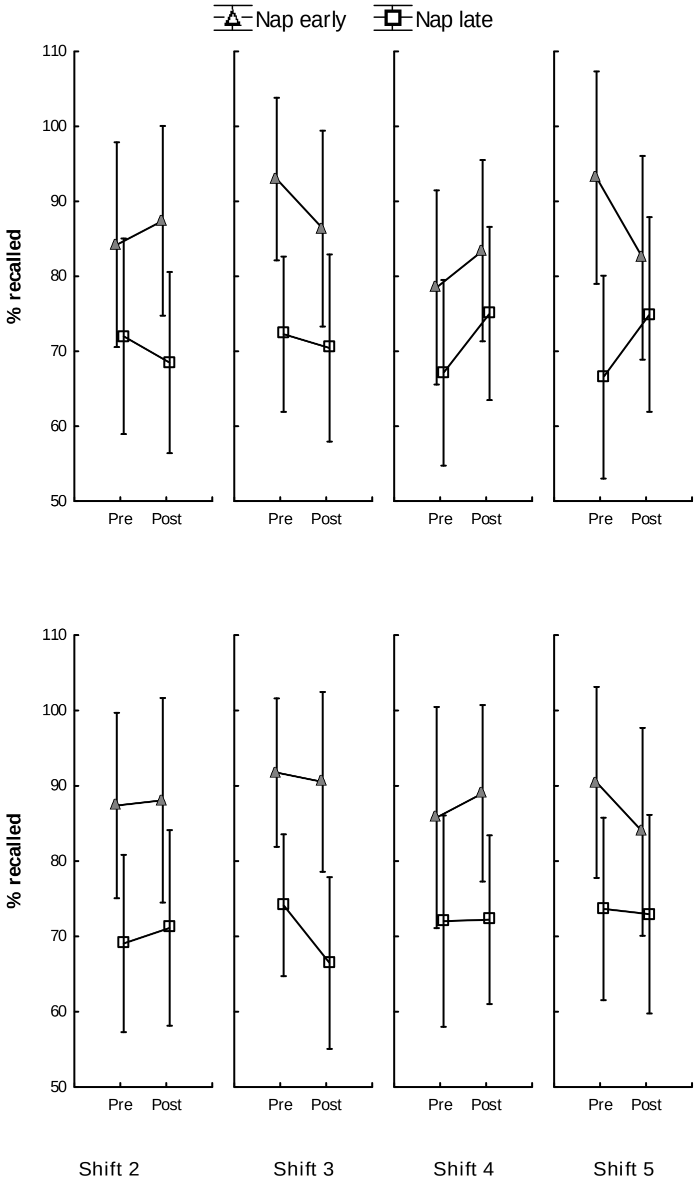

Figure 68: Percentage correctly recalled during the working memory recall test with long delay (top panel) and with a short delay (bottom panel) before and after the nap for both nap groups over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.12 Tympanic temperature

Temperature measures were significantly lower following the nap, when compared to measures taken before the nap (*Sleep inertia effect: p<0.01*: Table 35 and Figure 69). Tympanic temperature was also significantly higher in females, relative to males (*Sex effect: p<0.05*).

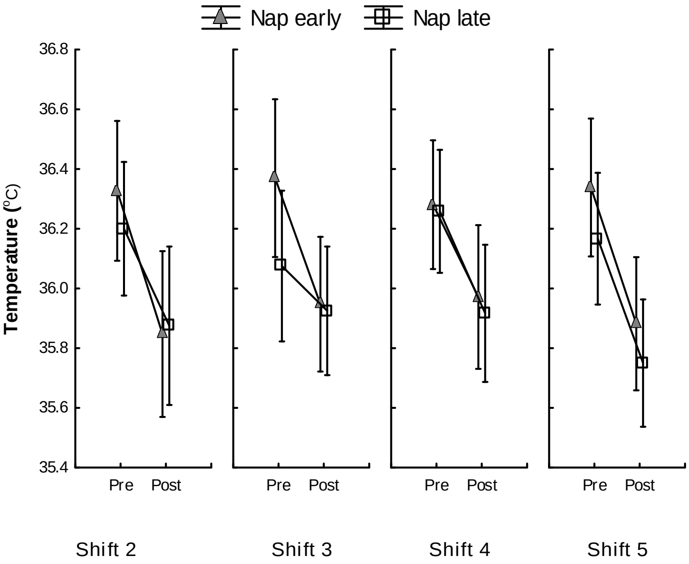

Figure 69: Tympanic temperature measures before and after the naps for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.13 Heart rate frequency

Heart rate measures were significantly higher following the nap when compared to pre nap measure (*Sleep inertia effect: p<0.05*: Table 35 and Figure 70 below). As with temperature measures, female participant heart rates, on average, were also significantly higher than the male participants.

4.1.3.8.14 Heart rate variability: r-MSSD

Heart rate variability decreased significantly post nap, relative to pre nap measures, (*Sleep inertia effects: p<0.05* Table 35 and Figure 71). There no other significant effects.

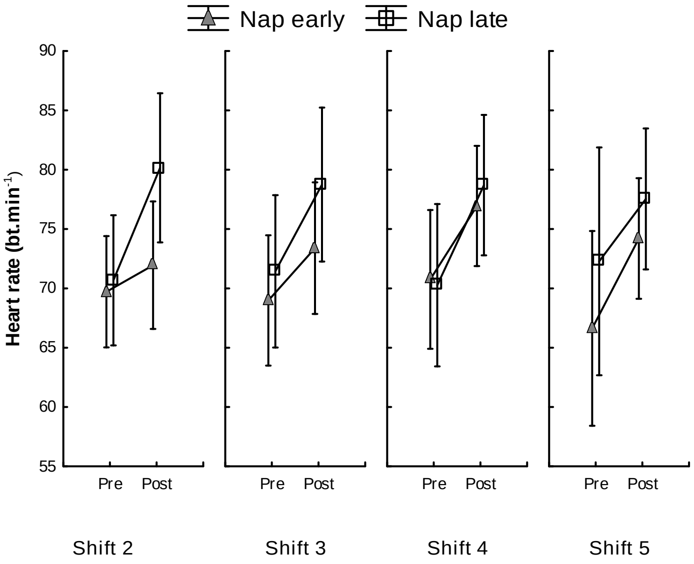

Figure 70: Heart rate frequency measures before and after the naps for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

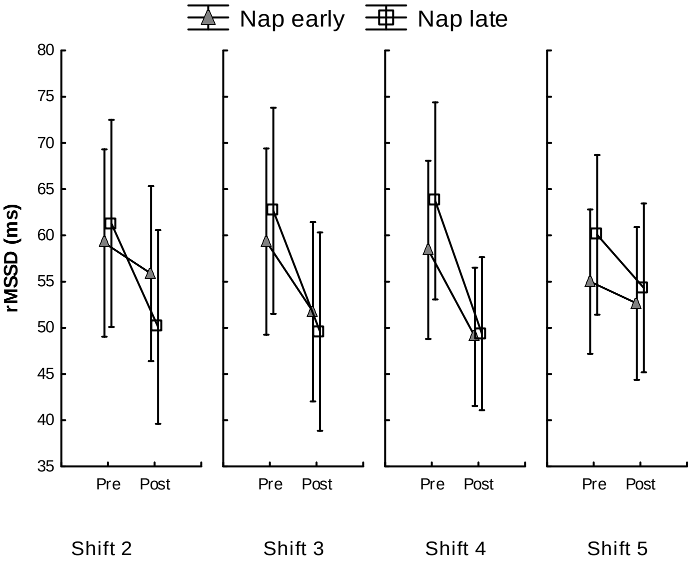

Figure 71: Heart rate variability measures (rMSSD) before and after the naps for both nap conditions over the four night shifts. Error bars denote a 95% confidence interval.

4.1.3.8.15 Subjective sleepiness

Ratings did not differ between condition, over time or over the shifts. However, female participants expressed significantly higher sleepiness than males (*Sex effect: p<0.01;* Table 35).

Accommodation time, visual detection test reaction time, high and low precision response time and continuous tracking reaction time did not reflect any sleep inertia effects or significant differences between the conditions or the days.

4.1.3.9 Reported sleep length and quality outside the laboratory

This section focuses on comparing reported sleep length for all conditions when participants were outside of the laboratory. Data were recorded for five days prior to the start of testing, during the night following the first afternoon shift and during the days following the first three night shifts. Data from the last shift was not included as this coincided with the end of the data collection period.

Initial analyses focused on determining the degree of homogeneity of reported sleep prior to the start of the data collection. Thereafter, the focus shifted to understanding the effects of transitioning from the first afternoon shift to the night shift. Lastly, the recovery sleep length for the three night shifts was analysed and reported on. Table 39 illustrates the actual, mean sleep length for the different periods. Thereafter, the results for the perceived sleep quality for the pre-data collection period and the actual data collection are presented.

4.1.3.9.1 Pre data collection sleep length

Reported sleep length before data collection did not differ significantly between conditions or over the pre data collection days (Table 36 and Figure 72).

Table 36: Statistical effects for the reported sleep length for all conditions prior to data collection. ns = non-significant result ($p>0.1$).

Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
ns	-	ns	-		ns	-	ns

4.1.3.9.2 Transition effects: afternoon to night shift and the effects on reported sleep

In the transition from the afternoon to the first night shift, sleep length differed significantly between the four experimental conditions (*Condition effect: $p<0.01$:* Table 37*).* More specifically, reported sleep length remained relatively consistent over the transition for the *Rolling rotation* condition, but significantly decreased for the *Fixed night, Nap early* and *Nap late* conditions with the start of the night shifts (*Condition by day effect: $p<0.01$:* Table 37 and Figure 72).

Table 37: Statistical effects for the reported sleep length for all conditions during the transition from the afternoon to night shift. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

Condition	Condition *Time	Condition*Dy	C*T*D	Time	Day	Time*Day	Sex
p<0.01*	-	p<0.01*	-	-	p<0.01*	-	ns

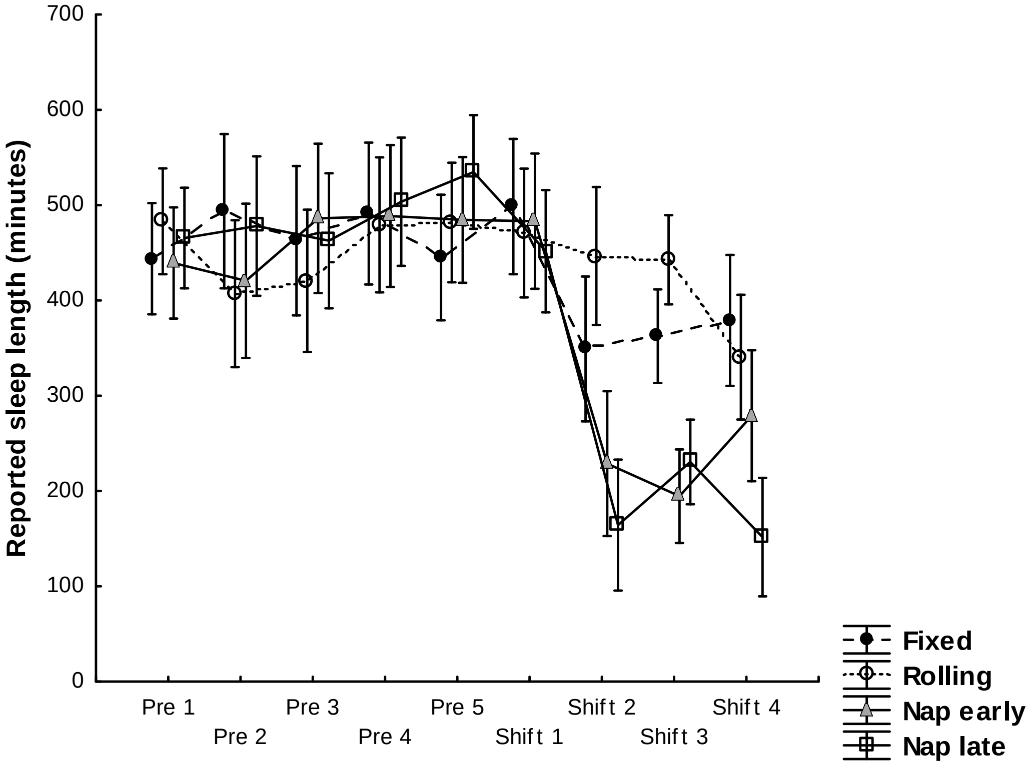

Figure 72: Total sleep length for all conditions during the pre-data collection period (PRE), the first afternoon shift (Shift 1,) and during the actual night shift (Shifts 2, 3 and 4). Error bars denote a 95% confidence interval.

4.1.3.9.3 Reported sleep length following the night shifts

Reported sleep length in both the *Fixed night* and *Rolling rotation* conditions was significantly longer post night shift compared to the two napping conditions (*Condition effect: p<0.01:* Table 38; Figure 72). Although there was no significant change in sleep length over the three recovery sleep periods (*Day effect*), sleep length did differ by condition over this period (*Condition by day: p<0.05*). Specifically, reported sleep length for both nap groups fluctuated over the three days, while in the *Rolling rotation* condition, sleep length gradually decreased as this group entered the same shift times as the *Fixed night* condition. With respect to the *Fixed night* group, sleep length tended to increase over the four night shifts. No other significant effects were found. However, the addition of the perceived nap length to the reported post shift sleep length in each nap condition resulted in there being no statistically significant differences between the four conditions (Table 38 and Table 39). However, the significant *condition by day* interaction mentioned above was still present.

Table 38: Statistical effects for the reported sleep length for all conditions during the night shift work period only. * = p<0.05. # = p<0.1. ns = non-significant result (p>0.1).

	Cond	Cond*Time	Cond*Day	C*T*D	Time	Day	Time* Day	Sex
Night shifts (without naps)	p<0.01*	-	p<0.05*	-	-	ns	-	ns
Night shift (with naps)	ns		P<0.01*			ns		ns

Table 39: Summary of mean reported sleep length prior to data collection, during the first afternoon shift, over the four night shifts, with and without perceived nap considered. * denotes a significant difference (*p<0.05*) with respect to the *Fixed night* condition. (**) denotes a significant difference (*p<0.05*) to the *Rolling rotation* condition.

	Prestudy sleep (mins: SD)	Post afternoon shift (mins: SD)	Post night shift (min: SD)	Post night shift + nap (min: SD)
Fixed night	468 (±108)	500 (±90)	354 (±80)	
Rolling	461 (±128)	475 (±86)	404 (±113)	
Nap early	465 (±81)	461 (±92)	244 (±101) * (**)	393 (±110)
Nap late	490 (±77)	484 (±134)	188 (±95) * (**)	365 (±96)

4.1.3.9.4 Reported sleep quality prior to and during the night shift work period

Perceived sleep quality did not significant differ between the conditions prior to or during the data collection period (Table 40 and Figure 73). However, perceived sleep quality was significantly lower with the start of the night shift: Post hoc tests revealed that there was a significant difference between the sleep quality on the day before the start of data collection (Pre 5) and Shift 2, which referred to the sleep following the first night shift.

Table 40: Statistical effects for the reported sleep quality for all conditions during the pre-data collection period and night shift work period. * = p<0.01. ns = non-significant result (p>0.1).

Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
ns	-	ns	-	-	p<0.01*	-	ns

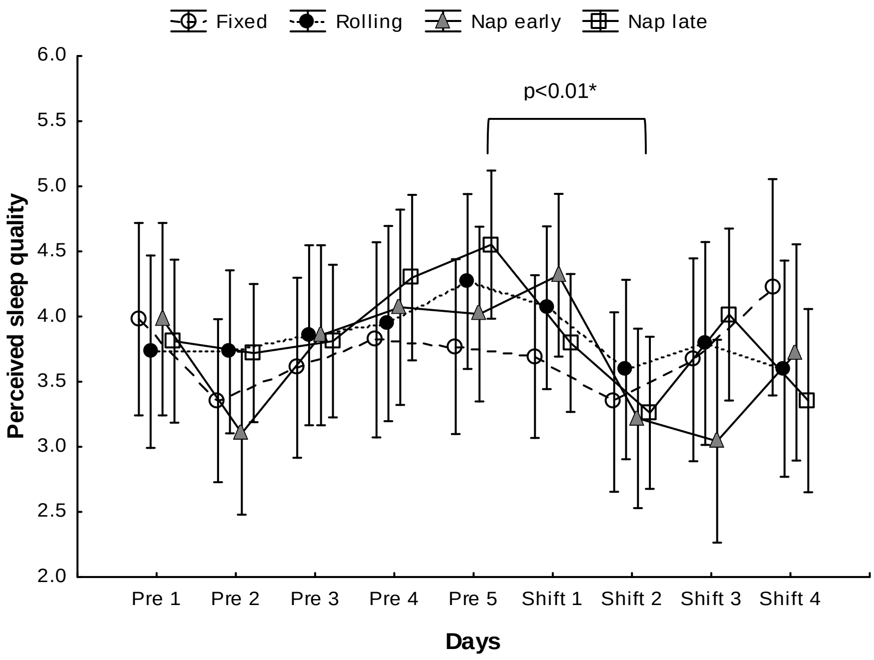

Figure 73: Mean perceived sleep quality for all conditions during the pre-data collection period (Pre) and the actual testing period (Shifts 1 to 4). Values closer to 1 = poor sleep quality, closer to 5 = excellent sleep quality. Brackets indicate a significant effect (*p<0.01*). Error bars denote a 95% confidence interval.

CHAPTER 5: DISCUSSION

5.1 OVERVIEW

The discussion of the results will follow the same order in which the hypotheses were presented; the general time of day/fatigue effects are discussed to determine the sensitivity (and validity) of the outcome measures selected to monitor the effects of working the night shift. This will be followed by any relevant cumulative effects, indicated by changes over the four night shifts. Understanding how the response variables change over the four night shifts is critical to gaining insights into whether cumulative sleep loss effects are present, whether a degree of adaptation to working night shifts has occurred or whether learning effects are present. Thereafter, the general condition effects (and the main focus of the study) are discussed, after which relevant interaction (*condition by time* and *condition by day*) are expanded upon. This section will conclude by interrogating other findings, providing possible explanations for these observations.

5.1.1 Time of day effects

5.1.1.1 Performance measures

Beading output permitted the participants to self-pace work speed, as there were no performance targets. The task was adopted as a performance measure in the current thesis. Beading performance slowed significantly (summarised in Table 41) during each shift, which is in line with previous work (Davy and Göbel, 2013). The remainder of the tests in the battery required the participants to perform maximally, as they were, in most cases experimenter-paced. With respect to those measures that reflected time of day effects, simple reaction time (Figure 38: p127), motor programming time (Figure 45: p132), high precision response time during the tapping test (Figure 46: p133) and the percentage of stimuli overlooked during the Visual detection test (40) (Figure 32: p122) all showed a general decline in performance during each shift. A similar trend towards a decrease in performance was observed for processing speed and % errors identified during the high resolution object recognition test (Figure 34: p124 and Figure 37, p126 respectively). These findings, specifically the simple reaction time (SRT) and high precision response time are in line with previous findings (Gillberg, 1984; Lamond *et al*., 2004; Davy and Göbel, 2013; Huysamen, 2014).

The beading task and the tests mentioned above were all relatively simple, required attention for a brief period of time (apart from the beading task), but did not overly tax the participants cognitively. Previous research has posited that under conditions of circadian desynchronisation and sleep loss such as night shift work, attention towards such tasks is typically reduced. This is due in part to reductions in circadian-modulated physiological arousal, as well as the effects of the actual task. With respect to the effects of the task, Pilcher *et al*. (2007), supported by Tremaine *et al.* (2010) explained that simpler tasks that are well rehearsed and tested repeatedly become uninteresting and unengaging, which in turn reduces the attention, motivation and effort devoted towards their completion. These effects were also likely enhanced by the increasing ratings of subjective sleepiness (Figure 59, p146) and reductions in physiological arousal, namely a reduced tympanic temperature and heart rate (Figure 51, p137 and Figure 53, p140) observed during each shift. The combination of these factors partially explains the reduction in performance in these particular measures.

In addition to the abovementioned tests, low precision response time during the tapping test, the percentage of correctly recalled numbers in both difficulties of the working memory test, processing speed during the low resolution object recognition test and the percentage of stimuli overlooked in Visual detection tests with 80 distractors all showed an overall decrease in performance over time with an error probability of below 10% (Table 41). These observations could be accounted for by the fact that these tasks were more challenging cognitively and required more attention and effort to complete than those mentioned previously, apart from the low precision response time. However, during the final two shifts, all of these tests, except for low precision response time, demonstrated a significant time effect in that performance generally decreased. This is partially explained by the fact that, by end of the testing period, the participants may have been experiencing cumulative sleep loss due to reductions in recovery sleep after each night shift, which is discussed in the Day (cumulative fatigue) effects section below (p168). Furthermore, the last two shifts also coincided with the *Rolling rotation* group assuming the same shift times as the *Fixed night* condition. Prior to this, the *Rolling rotation* group did not work the entire night shift, which may have reduced the strength of time of day effects for all four conditions.

In contrast to the above, eye accommodation time and choice reaction time, reaction time during the tracking tests (both levels of difficulty) and reaction times during Visual detection task (both difficulties) were not sensitive to time of day/fatigue. The accommodation test, one of the longest tasks in the battery, required participants to remain attentive to changes in target location (near or far) and to make a decision on the response. This constituted the choice reaction time component of the test. The addition of a decision making component to this test could account for the lack of change in both outcome measures.

During both difficulties of the visual detection test, participants were required to respond to the presentation of the critical stimulus amongst a host of distracting stimuli. Reaction times in both difficulties were consistent across the shifts, but this only included reaction times for stimuli that were detected. Therefore, despite the reaction time performance remaining consistent, the percentage of stimuli overlooked increased. This illustrates that participants, irrespective of condition, may have experienced increased lapses in attention and the occasional (potential) intrusions of sleep during task performance. In addition, there doesn’t appear to be evidence of any kind of speed accuracy trade off in this test, as speed did not improve significantly while the percentage of stimuli overlooked increased. These findings have implications for tasks that require selective attention.

Similarly, the continuous tracking test performance in both versions was not sensitive to the time of day effects. This test required constant attention without a break to maintain the “car” on the target line, irrespective of the steering sensitivity. Additionally, when compared to all the other tests, the tracking tests were probably the most “interesting” as most participants had little or no experience in driving a car. The continuous nature of the test, accompanied by its game-like appearance could explain why tracking performance and motor control did not deteriorate during each shift. The minimal change in performance could also be attributed to a learning effect, which is discussed further in the cumulative fatigue section below. Lastly, all of these tests were also short in duration so participants could remain attentive to the tests, in spite of mounting sleep pressure and reduced arousal before getting to rest (stop performing the test).

5.1.1.2 Physiological measures

As summarised in Table 41, all physiological measures, apart from the normalised Low frequency (LF nu) responses, revealed the effects of the time of day generally, under the influence of the natural circadian down regulation irrespective of the condition. Temperature measures decreased in all conditions, particularly those that ran over the night (Figure 51: p137), with measures reaching a minimum between 04h00 and 06h00, a finding that is in line with previous research (Wyatt *et al.,* 1999; Wright *et al*., 2002; Westensen *et al*., 2002; Davy and Göbel, 2013). Additionally, the tympanic temperature was also sensitive to the natural increase that occurs in the early morning, specifically in the *Nap late* condition. Similar trends were observed in the heart rate frequency measures (Figure 53, p140), evidenced in previous night shift and sleep deprivation research (Furlan *et al*., 1990; Furlan *et al*., 2000; Dutheil *et* al., 2012; Davy and Göbel., 2013).

With respect to all heart rate variability, responses were consistent for all the different conditions. The time domain measure, r-MSSD increased over time during both the testing and working periods (Figure 54, p142), which is indicative of the increasing heart rate variability and likely a reflection of increasing parasympathetic activation and an associated increased sleepiness (Munakata et al., 2000; Dutheil et al., 2012). Previous research has also demonstrated that an increased HRV was highly correlated with decrements in Psychomotor vigilance test performance under conditions of sleep loss and circadian modulated reductions in alertness levels (Chua et al., 2012). The similar observation made in this study (with respect to HRV) could partially account for the decrements in the performance measures outlined above. With respect to LF nu, responses did not change with time on shift during the tests (Table 30, p143) or the work periods (Table 31, p144).

Taken together, these results support the typical reduction in physiological arousal that occurs during the night shift under the influence of the innate circadian clock. Furthermore, the physiological down regulation as a result of natural circadian-related changes partially account for the changes in the performance measures (discussed above) and the subjective measures (discussed below).

5.1.1.3 Subjective measures

There was a significant increase in sleepiness (Figure 58, p146) during each shift generally for all conditions, apart from a significant *condition by time* effect which is discussed in Interaction effects section. Increased ratings of subjective sleepiness have been reported extensively in simulated and real world shift work settings (Sallinen *et al*., 1998; Purnell *et al*., 2002; Axelsson *et al*., 2004; Smith-Coggins *et al*., 2006; Lovato *et al*., 2009; Waage *et al*., 2012; Davy and Göbel, 2013; reviewed in Åkerstedt *et al*., 2014), with the interaction of the time of day, circadian factors and extended wakefulness being identified as likely causes for increasing sleepiness.

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Table 41: A summary of the statistical effects for time of day (General and final). Cells highlighted in green indicate an error probability of (p<0.05 or p<0.01), orange indicates an error probability between 0.05 and 0.1. Arrows demonstrate the general change in the response variable. “=” signifies no change.

Type of variable	Dependent variable	Difficulty	Outcome measure	Time effect (General)	Response of variable over time	Time effect (Final two shifts)	Response of variable over time
Performance	**Beading task**	–	*Beading performance*	<0.01*	↓	<0.01*	↓
Visual perception measures	**Accommodation test**	–	*Accommodation time*	0.15	=	0.67	=
		–	*Choice reaction time*	0.13	=	0.21	=
	Visual detection test	80 distractors	*Median reaction time*	0.25	=	0.66	=
		40 distractors	*Median reaction time*	0.89	=	0.95	=
		80 distractors	*% of stimuli overlooked*	0.06#	↑	0.04*	↑
		40 distractors	*% of stimuli overlooked*	<0.01*	↑	0.11	=
	Objection recognition / reading test	Low resolution	*Processing speed*	0.09#	↓	<0.01*	↓
		High resolution	*Processing speed*	0.01*	↓	<0.01*	↓
		Low resolution	*% errors identified*	0.17	=	<0.01*	↓
		High resolution	*% errors identified*	0.01*	↓	<0.01*	↓
	Simple reaction test	–	*Median reaction time*	<0.01*	↑	<0.01*	↑
Cognitive measures	**Working memory digit span test**	Long delay	*% correctly recalled*	0.07#	↓	<0.01*	↓
		Short delay	*% correctly recalled*	0.09#	↓	0.02*	↓
Psychomotor measures	**Modified tapping test**	–	*Motor programming time*	<0.01*	↑	<0.01*	↑
		–	*High precision Response time*	<0.01*	↑	0.35	=
		–	*Low precision Response time*	0.08#	↑	0.34	=
	Continuous tracking test	High sensitivity	*Median reaction time*	0.24	=	0.71	=
		Low sensitivity	*Median reaction time*	0.98	=	0.39	=
Physiological	**Tympanic temperature**	–	*Body temperature*	<0.01*	↓	<0.01*	↓
	Heart rate frequency	Test battery	–	<0.01*	↓	<0.01*	↓
		Work periods		<0.01*	↓	<0.01*	↓
	r-MSSD	Test battery	*Time domain analysis*	<0.01*	↑	<0.01*	↑
		Work periods		<0.05*	↑	<0.01*	↑
	Normalised Low frequency power	Test battery	*Frequency domain analysis*	0.47	=	0.74	=
		Work periods		0.37	=	0.18	=
Subjective	**Karolinska Sleepiness**	–	*Subjective sleepiness*	<0.01*	↑	<0.01*	↑

5.1.2 Cumulative (day) effects over the four night shifts

In the current set up, there was a significant reduction in beading performance over the four night shifts (*$p<0.05$* Figure 23, p115 and summarised in Table 43 below). The beading task was the only task that allowed the participants to self-pace their performance, with this result likely being attributed to two possible explanations. Firstly, the beading task was monotonous and repetitive, which may have resulted in a reduction in the participant interest in completing it. Secondly, the decreased output could be reflective of the cumulative sleep loss that the participants experienced over the four night shifts. This observation is partially supported by the reduction in reported sleep following the transition from the afternoon shift to the night shift phase (Table 37, p159 and Figure 72, p159). This is a commonly reported downside associated with working night shifts (Åkerstedt *et al*., 1991; Holmes *et al*., 2001; Davy and Göbel., 2013) and stems mainly from the participants attempting to sleep against the alerting signals of the circadian rhythm and the social and general societal demands of the surrounding environment.

In addition to this, motor programming time significantly increased as a function of the four night shifts (Figure 44, p132). This outcome measure was determined by building the difference between response times for the predictable targets and those of the unpredictable targets. In this instance, although the result appears to be a negative one, as motor programming time slowed, there is an alternative explanation. Following a post hoc test (Table 42, below), the results for which are presented below, the speed with which participants responded to the predictable target in the centre of the screen significantly decreased during the four shifts (Figure 74, right graphic). In contrast, response time for the unpredictable targets remained consistent (Figure 74, left graphic). As such, the difference between the two would reflect an increase in motor programming time, when in actual fact, it reflects a consistent response time for unpredictable targets and increasing response times for the predictable targets. This shows a clear learning effect associated with the predictable element of the tapping test.

Table 42: Statistical effects for response time to the unpredictable target (light grey cells) and predictable (dark grey cells) targets during the tapping task. * = p<0.01. # = p between 0.05 and 0.1. ns = p>0.1.

	Condition	Condition*Time	Condition*Day	C*T*D	Time	Day	Time*Day	Sex
Unpredictable targets	ns	ns	ns	ns	ns	p=0.09#	ns	ns
Predictable targets	ns	ns	ns	ns	p<0.01*	p<0.01*	ns	ns

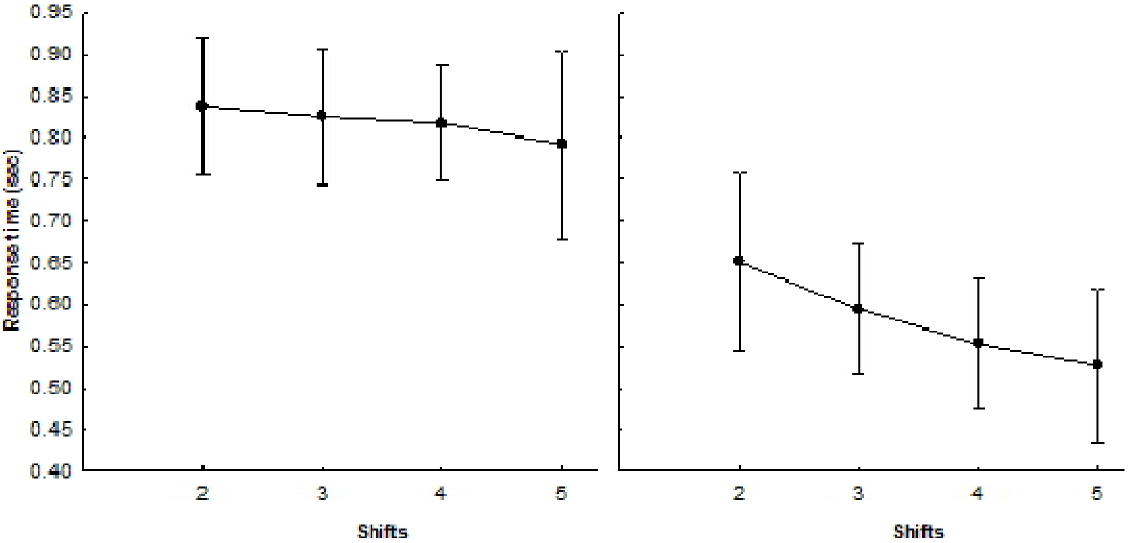

Figure 74: Response time to the unpredictable targets (left panel) and the predictable targets (right panel). Error bars denote a 95% confidence interval.

Performance during the high and low sensitivity tracking tests improved significantly over the four night shifts. It was evident that the majority of the participants had not experienced a driving simulator of this nature before, which resulted in large variability in performance initially and more consistent performance during subsequent days of data collection (Figure 47: p134 and Figure 48: p135 respectively). A similar improvement was observed in both object recognition tests in that the percentage of errors identified in both difficulties increased, but only during the third and fourth shift (Figure 35, p125and Figure 36, p126). In contrast, the processing speed during both object recognition tests did not change significantly during the four shifts, which shows that the participants focused more on error identification than skim-reading during this test.

Memory performance during the working memory test with a short delay improved on average over the course of the night shifts (Figure 42: p130), which was likely the result of an improved rehearsal strategies developed over the repeated testing. Lastly, reaction times (Figure 25: p117 and Figure 27: p118) and the percentage of stimuli overlooked (Figure 30: p120 and Figure 31: p121) during both difficulties of the visual detection test in all conditions also demonstrated improvements over the four night shifts.

The abovementioned performance measures are likely indicative of a learning effect, which would have occurred both within the shifts and over the course of the four night shifts. This effect is a common artefact of highly repetitive testing arrangements (as discussed in Grandjean, 1979; Blatter and Cajochen, 2007). However, similar improvements in performance measures have previously been attributed to partial circadian adaptation to working consecutive night shifts (Lamond *et al*., 2004). In the current study, although this could be an explanation for the observed performance improvements, there were no significant physiological and subjective changes to support this hypothesis.

In contrast, certain perceptual measures including accommodation time and choice reaction time, simple reaction time and processing speed during both difficulties of the object recognition test did not change significantly over the four shifts. Additionally, memory performance during the more difficult version did not change significantly over the data collection period, despite evidence of this measures sensitivity to fatigue over each shift (discussed in the time of day section). Similarly, response times to both the low and high precision targets in the tapping test did not show a significant change over the four shifts. It can therefore be concluded that these tests were robust enough to limit learning effects during the testing phase. It is also possible that these tests were also insensitive to the effects of cumulative fatigue. The results discussed in this section highlight two noteworthy observations. The first is that self-paced, repetitive tasks, such as the beading task, appear to be more sensitive to cumulative fatigue than short duration, externally-paced tasks (Blatter and Cajochen, 2007). Secondly, highly repetitive testing over multiple days may result in a learning effect, which may mask the effects of cumulative fatigue (Jewett *et al*., 2001). Considerations around how to manage the cumulative fatigue effects in real-world, self-paced tasks are therefore imperative.

Table 43: A summary of the effects for the four consecutive shifts (*Day effects*). Cells highlighted in blue indicates a significant effect (p<0.05), orange indicates an error probability of between 0.05 and 0.1. Arrows demonstrate the general change in the response variable, whereas "=" signifies no change.

Type of variable	Dependent variable	Difficulty	Outcome measure	Day effect (General)	Response of variable over four shifts	Day effect (Final two shifts)	Response of variable over last two shifts
Performance	**Beading task**	–	*Beading performance*	<0.05	↓	0.73	=
Visual perception measures	**Accommodation test**	–	*Accommodation time*	0.12	=	0.95	=
		–	*Choice reaction time*	0.19	=	0.5	=
	Visual detection test	80 distractors	*Median reaction time*	<0.01*	↓	0.11	=
		40 distractors	*Median reaction time*	<0.01*	↓	0.01*	↓
		80 distractors	*% of stimuli overlooked*	<0.01*	↓	0.01*	↓
		40 distractors	*% of stimuli overlooked*	<0.01*	↓	0.01*	↓
	Objection recognition / reading test	Low resolution	*Processing speed*	0.95	=	0.87	=
		High resolution	*Processing speed*	0.13	=	0.07#	↑
		Low resolution	*% errors identified*	<0.01*	↑	0.18	=
		High resolution	*% errors identified*	<0.01*	↑	0.18	=
	Simple reaction test	–	*Median reaction time*	0.33	=	0.09#	↓
Cognitive measures	**Working memory digit span test**	Long delay	*% correctly recalled*	0.29	=	0.78	=
		Short delay	*% correctly recalled*	0.01*	↑	0.02*	↑
Psychomotor measures	**Modified tapping test**	–	*Motor programming time*	<0.01*	↑	0.5	=
		–	*High precision Response time*	0.22	=	0.82	=
		–	*Low precision Response time*	0.63	=	0.97	=
	Continuous tracking test	High sensitivity	*Median reaction time*	<0.01*	↓	0.11	=
		Low sensitivity	*Median reaction time*	<0.01*	↓	0.12	=
Physiological	**Tympanic temperature**	–	*Body temperature*	0.38	=	0.4	=
	Heart rate frequency	**Test battery**	–	0.66	=	0.57	=
		Work periods		0.43	=	0.63	=
	r-MSSD	**Test battery**	*Time domain analysis*	0.34	=	0.21	=
		Work periods		0.39	=	0.23	=
	Low frequency power (normalised)	**Test battery**	*Frequency domain analysis*	0.67	=	0.43	=
		Work periods		0.66	=	0.44	=
Subjective	**Karolinska Sleepiness**	–	*Subjective sleepiness*	0.15	=	0.43	=
Post shift sleep length	–	–	*Reported sleep length*	0.01*	↓	-	-

5.1.3 Condition effects

This section will discuss any significant differences observed between the conditions generally. Where appropriate, interaction effects (namely *Condition by time* or *Condition by day* effects) will be included. The relevant summary of the statistical effects for all the outcome measures and the corresponding responses are summarised in Table 44 below.

5.1.3.1 Effects of the Rolling rotation condition on beading performance

The *Rolling rotation* group produced a significantly higher beading output when compared specifically to the *Nap late* condition, over the four shifts generally and during the final two shifts (Figure 22: p114). There are two possible reasons for this observation. Firstly, the beading task in this study was the only self-paced task, but one which required constant attention and concentration to complete. Such tasks often reflect the level of alertness and motivation under conditions of sleep loss better than experimenter-paced tests due to need for self-directed focus (bottom up) to the task over an extended period of time (Pilcher *et al*., 2007). The controlled attention hypothesis holds that task performance is generally better when a performer is interested in the task, which will result in them increasing their effort to overcome sleepiness and complete the task. This supports the conclusions made by Tremaine *et al*. (2010). Therefore, the higher output in the *Rolling rotation* condition could be the result of this group possessing greater inherent interest in this task, compared to the other conditions.

Secondly, when the dual impact of the circadian and homeostatic processes is considered, the higher output in the *Rolling rotation* condition could be explained by the fact that the group spent less time working at times of the day that would negatively affect alertness, motivation and the monotony associated with performing the task. Due to the self-paced nature of the task, any factors that affect motivation, such as extended wakefulness and circadian-related reductions in alertness would likely negatively affect the engagement in and the output from a task such as beading. This was clearly demonstrated in the significantly lower performance output for the *Nap late* group, the condition that started their shift at midnight. This late start time likely resulted in the group entering the night shift in an already compromised or fatigued state. Although the general recommendations for night shift start times varies from 21h00 to 00h00 (Knauth *et al*., 1980a; Kecklund and Åkerstedt, 1995; Åkerstedt, 1998; EU Working time directive, 2003), it is evident from this result that the shift start time of midnight may be too late, with the reduced output likely the result of the combination of extended wakefulness and time of day effects.

5.1.3.2 . Effects of the Nap Late night shift regime on memory performance

During the working memory test with the longer delay, the percentage of numbers correctly recalled was significantly lower (statistically) in the *Nap late* group when compared to the *Fixed night* condition (Figure 39: p128). Mean performance was possibly better in the *Nap early* and *Rolling rotation* conditions as well, with the error probability falling between 5 and 10%. With respect to the task with the shorter recall delay, again the *Nap early* condition performed significantly better than the *Nap late* (Figure 41, p130), with *Fixed night* and *Rolling rotation* conditions also performing numerically better, but not statistically so (*p=0.051* and *p=0.06* respectively). As with the beading task performance, the late shift start time for the *Nap late* condition may have resulted in an extended period of wakefulness before starting the shift. This extended wakefulness, coupled with the time of day influences could have been the cause of the reduced capacity to memorise and recall the numbers. This observation was supported by similar findings in previous research, where working memory performance decreased as a function of time of day (Folkard 1975; Johnson *et* al., 1992; Smith-Coggins *et al*., 2006) and time awake (Polzella, 1975).

Despite there being no significant differences in memory performance between the four conditions during the initial habituation afternoon, the *Nap late* group's performance during the night shifts was significantly compromised. Together with the reduced beading performance, it is clear that the late shift start time compromised the *Nap late* group's ability to perform the continuous and repetitive beading task, while also negatively affecting a fundamental cognitive element of the information processing chain.

Table 44: A summary of the general condition effects for the four night shifts. Red indicates a significant effect ($p<0.05$), orange indicates an effect between 0.05 and 0.1. FN: Fixed Nightshift, RR: *Rolling rotation*, NE: Nap Early, NL: Nap Late. Arrows signify a general change in the response variable, "=" signifies no change.

Type of variable	Dependent variable	Difficulty	Outcome measure	Condition effect (General)	Response of variable by condition	Condition effect (Final two shifts)	Response of variable by condition
Performance	**Beading task**	–	*Beading performance*	<0.01*	RR ↑ than NL	0.04*	RR ↑ than NL
Visual perception measures	**Accommodation test**	–	*Accommodation time*	0.63	=	0.67	=
		–	*Choice reaction time*	0.14	=	0.14	=
	Visual detection test	80 distractors	*Median reaction time*	0.57	=	0.35	=
		40 distractors	*Median reaction time*	0.19	=	0.09#	NE ↑ than FN
		80 distractors	*% of stimuli overlooked*	0.08#	NL ↓ than NE	0.15	=
		40 distractors	*% of stimuli overlooked*	0.28	=	0.42	=
	Objection recognition / reading test	Low resolution	*Processing speed*	0.48	=	0.57	=
		High resolution	*Processing speed*	0.43	=	0.38	=
		Low resolution	*% errors identified*	0.56	=	0.58	=
		High resolution	*% errors identified*	0.7	=	0.56	=
	Simple reaction test	–	*Median reaction time*	0.46	=	0.67	=
Cognitive measures	**Working memory test**	Long delay	*% correctly recalled*	0.02*	NL ↓ than FN	0.04*	NL ↓ than FN
		Short delay	*% correctly recalled*	0.02*	NL ↓ than NE	0.03*	NL ↓ than FN
Psychomotor measures	**Modified tapping test**	–	*Motor programming time*	0.16	=	0.23	=
		–	*High precision Response time*	0.37	=	0.25	=
		–	*Low precision Response time*	0.34	=	0.24	=
	Continuous tracking test	High sensitivity	*Median reaction time*	0.18	=	0.19	=
		Low sensitivity	*Median reaction time*	0.39	=	0.33	=
Physiological	**Tympanic temperature**	–	*Body temperature*	0.28	=	0.3	=
	Heart rate frequency	**Test battery**	–	0.52	=	0.82	=
		Work periods		0.54	=	0.80	=
	r-MSSD	**Test battery**	*Time domain analysis*	0.41	=	0.36	=
		Work periods		0.47	=	0.41	=
	Low frequency power (normalised)	**Test battery**	*Frequency domain analysis*	0.15	=	0.40	=
		Work periods		0.36	=	0.66	=
Subjective	**Karolinska Sleepiness**	–	*Subjective sleepiness*	0.07#	NL ↓ than FN	0.18	=
Post shift sleep length	**Post shift sleep length**	–	–	<0.01*	NL & NE ↓ than RR and FN	-	-

5.1.3.3 Effects of nap timing on perceived sleep length and quality during the naps

The *Nap early* condition in the current study reported a significantly shorter nap length than the *Nap late* group (145 ±30 minutes vs 180 ±25 minutes respectively) (Figure 60: p148). This was accompanied by higher perceived quality of sleep in the *Nap late* condition relative to the *Nap early* condition (Table 34, p147). Previous research has reported that naps taken during or around the nadir (03h00 to 06h00) tend to be more restorative, in that they are better quality and longer than earlier naps (Matsumoto, 1981; Åkerstedt and Folkard, 1997; Caldwell, 2002; Takeyama *et al*., 2004; Kubo *et al*., 2007). It is likely that the extended wakefulness and subsequent increased sleep propensity in the *Nap late* group could account for this observation. These findings emphasise the importance of considering the timing of the nap in order to maximise the quality of sleep obtained.

5.1.3.4 Effect of different night shift regimes on reported post shift sleep

With the start of the night shift work period, there was a significant reduction in reported sleep length outside of the laboratory. Additionally, post shift sleep was significantly shorter in both nap conditions when compared to both *Fixed night* and *Rolling rotation* conditions (Figure 72, p159 and Table 39, p160), which is a reported challenge associated with the inclusion of naps at night (Matsumoto and Harada, 1994; Sallinen *et al*., 1998; Bonnefond *et al*., 2001). The findings of the current study support those of Matsumoto and Harada (1994), Dauret and Foret (2004) Borges *et al*. (2009) during which long naps (+2hours) taken during the night reduced day time sleep significantly. However, they contradict the observations of the Takeyama *et al*. (2002) study, where no negative effects of a two-hour nap on subsequent day time sleep were reported.

The truncated sleep in this study was likely due to a number of factors, the first of which was the length of the naps. In a month long study on the sleeping behaviours of night time nurses, Dauret and Foret (2004) found that naps or anchor sleeps taken at night and lasting 150 minutes significantly reduced the length of day time sleep (194 minutes for the nap group vs 359 minutes for the no nap group). In contrast, other studies in which shorter naps have been applied did not report any significant reductions in post shift sleep (Sallinen *et al*., 1998; Bonnefond *et al*., 2001; Purnell *et* *al*., 2002; Smith *et al*., 2007; Signal *et al*., 2009). This supports the observation that elongated naps (+2 hours) during night shifts may facilitate the dissipation of sleep pressure by providing enough time for individuals to enter into slow wave sleep (Lovato and Lack, 2010). Shorter naps (less than 40 to 60 minutes) may limit the opportunity for slow wave sleep, which could explain the discrepancy between this study and others that have applied shorter naps.

The observed difference between reported sleep lengths in both nap groups when compared to the *Rolling rotation* condition specifically could also be partially accounted for by the difference in shift start and end times of this group. The fact that the 2nd and 3rd shifts of the *Rolling rotation* ended earlier than all the other conditions (02h00 and 04h00 respectively) would have enabled the *Rolling rotation* condition to obtain more sleep during part of the habitual night when compared to the two nap conditions who would have had to attempt to sleep against the alerting signals of the circadian clock (Figure 72; p159). This observation supports previous findings by Bjerner *et al*. (1948 as cited in Rosa *et al*., 1996) during which the authors reported that sleep length was significantly longer in shifts that ended at 04h00, as opposed to 05h00.

The second contributing factor to reduced day time sleep was the proximity of the nap to end of shift and the opportunity to obtain sleep again. In both the *Nap early* and *Nap late* conditions, this period was only four hours. As such and in line with two process model (Borbely and Acherman, 1999) sleep pressure at end of the night shift was likely lower in both nap conditions compared to the *Fixed night* and *Rolling rotation* conditions who had not slept at all during the night shifts. Furthermore, the concomitant wakefulness promoting signals of the circadian rhythm would have interfered with day time sleep in both nap conditions as both nap conditions ended work later than the *Fixed night* and *Rolling rotation* conditions. Additional social responsibilities or disturbances that were beyond the control or interest of this thesis could also have contributed to this reduced sleep in all of the conditions. Lastly, the *Nap late* group perceived to have slept significantly longer and better than the *Nap early* (Figure 60; p148). In conjunction with the abovementioned factors, this finding may also account for the truncated post shift sleep, despite their being no statistically significant differences between the two nap groups.

5.1.3.4.1 Effects of combining perceived nap sleep length and post shift sleep length

Despite the fact that post shift sleep was shorter in both nap conditions compared to the other two conditions, when the perceived sleep length during the naps were added, the total amount of sleep per day did not significantly differ from the post shift sleep reported in the *Fixed night* or *Rolling rotation* conditions (Table 39, p160). Matsumoto and Harada (1994) reported similar findings and stressed this to be advantageous as the reduced need for day time sleep frees up time for other social responsibilities. The findings of this study and others (Shea *et al*., 2014; MacDonald *et al*., 2013; Jackson *et al*., 2014) support the inclusion of elongated naps during the night shifts as a way of supplementing the already truncated day time sleep, which ensures that the total amount of sleep obtained per day is extended when compared to no nap at all. Despite this observation, both nap conditions and the *Fixed night* condition experienced a significant reduction in total reported sleep time during the night shift phase, when compared to normal sleep.

5.1.4 Interaction effects

This section will discuss any significant interaction effects (*Condition by time* or *Condition by day*), most of which were associated with the napping conditions. The interaction effects for the performance measures are discussed under the sleep inertia section below, as this was a likely explanation for most of the effects.

5.1.4.1 Condition by time interactions: Physiological responses

Tympanic temperature measures showed a general decrease over each shift, but responses differed between the experimental conditions. Temperature measures, although lower following both sleep periods in the nap conditions, stabilised and increased following the nap in the *Nap late* condition, when compared to *Fixed night*, *Rolling rotation* and *Nap early* conditions in which measures continued to decrease towards the end of the shift (Figure 52, p138). Heart rate frequency decreased over the course of each shift in both the *Fixed night* and *Rolling rotation* conditions. Similar responses were observed for both nap groups, but following the naps, heart rate measures were higher in both the *Nap early* and *Nap late* conditions (Figure 53, p140). Additionally, rMSSD increased generally over each shift in both test and work periods in the *Fixed night* and *Rolling rotation* conditions (Figure 54, p142) and decreased following the naps. The concomitant reduction in r-MSSD and an increase in heart rate frequency (Figure 53, p140) following the naps in both the *Nap early* and *Nap late* groups could indicate an increased physiological arousal which could have contributed to the reduction in subjective perceptions of sleepiness (Figure 58, p146). This supports the findings of Freitas *et al*. (1997) who demonstrated that heart rate variability tends to decrease significantly upon awakening. However, these authors attributed this to the effects of sleeping supine (which increases HRV) as compared to being awake and standing (which decreases HRV), and not solely as a result of time of day.

LFnu measures differed for the different conditions during the test batteries for final two shifts: in the *Nap early* condition, LF nu was lower during the initial part of the shift and increased after the nap, when compared to the *Fixed night, Rolling rotation* and *Nap late* conditions. This finding possibly indicates a reduced sympathetic activation in this group during the initial part of the shift. Previous research (Furlan *et* al., 2000) concluded that reduced sympathetic activation during the night shift, denoted by reduced LFnu responses, was associated with increased sleepiness and reduced arousal. During the work periods, a similar trend (as described above) with respect to the *Nap early* condition was found. Additionally, LFnu responses for the *Nap late* condition were similar to those of the *Fixed night* and *Rolling rotation* conditions during the initial part of each shift, but decreased between the fourth and fifth work periods (Figure 56, p144). This was may be due to an increased high frequency component, which has been associated with increased parasympathetic activation and increasing sleepiness which may have predominated towards the end of the shift (Takeyama *et al*., 2002).

5.1.4.2 Effects of nap conditions on subjective sleepiness

In the current study, under simulated night shift conditions, the inclusion of both the early and late naps resulted in a general, but not significant reduction in overall subjective sleepiness ($p<0.07$) when compared to *Fixed night* and *Rolling rotation* conditions (Figure 57: p145). More specifically, this difference became manifest after participants awoke from the nap, supported by the *condition by time* interaction (Figure 59, p146). This is in accordance with previous research during which shorter and longer naps reduced feelings of subjective sleepiness post nap (Takeyama *et al*., 2002; Takeyama *et al*., 2004; Smith *et al*., 2007; Lovato *et al*., 2009; Davy and

Göbel, 2013; Volpp *et al*., 2012). In contrast, others researchers have reported no reduction in subjective sleepiness levels following naps (Rosekind *et al*., 1994; Sallinen *et al*., 1998; Purnell *et al*., 2002; Howard *et al*., 2010) or protected sleep periods during night shift conditions (Shea *et al*., 2014). However, the inclusion of individuals who are accustomed to working night shifts, the effects of real world contextual demands (Rosekind *et al*., 1994; Purnell *et al*., 2002; Shea *et al*., 2014), the methodological differences, particularly the shorter duration naps (Rosekind *et al*., 1994; Sallinen *et al*., 1998; Purnell *et al*., 2002; Howard *et al*., 2010) and varying degrees of sleep loss prior to nap interventions may account for the inconsistencies between these abovementioned studies and the current one.

With respect to the current results, the naps in both the *Nap early* and *Nap late* conditions would have limited the duration of continuous wakefulness, an assertion that is in agreement with the findings of Borges *et al.* (2009). Furthermore, the mere act of sleeping during the nap, which the participants perceived to have done, may have alleviated physiological sleepiness which positively influenced subsequent perceptions (Smith *et al*., 2007). Additionally, the length of the nap period may have provided the opportunity for at least one or even two full NREM-REM sleep cycle to be completed, which has been reported to last between 70 and 100 minutes (Carskadon and Dement, 2000). Previous research has emphasised that the initial part of sleep is typically the deepest as it contains a large proportion of slow wave sleep (as cited in Naitoh and Angus, 1987), which could further explain why the participants in the napping conditions experienced improved perceptions upon awakening (Carskadon and Dement, 2000). This was likely attributable to the perceived length of the nap opportunity sleep during the *Nap early* and *Nap late* conditions which were 145 (±31) minutes and 180 (±26) minutes respectively.

Purnell and colleagues (2002) concluded that longer naps would most likely improve subjective sleepiness, after a 20-minute nap implemented during the night shift improved objective performance only. This assertion is supported by studies which have found that extended naps (<2 hours) significantly reduce sleepiness (Takeyama *et al*. 2002; Takeyama *et al*., 2004; Volpp *et al*., 2012), but others have also found positive effects following shorter naps (Smith *et al*., 2007; Lovato *et al*., 2009; Davy and Göbel, 2013). These observations highlight how the varying methodological approaches adopted to study the effects of napping have contributed to making universal recommendations challenging. They further highlight the possible confounding and individual-specific nature of self-perceptions of sleepiness, which can be affected by a host of contextual factors. This is not to say that they are not useful and important. However, their interpretation should be made with caution and additional, more objective measures should be applied (if practically possible).

With reference to nap timing, the *Nap early* group awoke in the nadir, yet still reported a reduction in subjective sleepiness. In contrast, the *Nap late* condition awoke at a time when the alerting signals from the endogenous (circadian upswing) and exogenous factors favoured wakefulness (07h20). As such, the combined effect of the sleep obtained during the nap and the time of waking positively influenced subjective sleepiness in the *Nap late* group. This was supported to some extent in the observed increase in heart rate frequency and concomitant decrease in heart rate variability mentioned previously.

5.1.4.3 Sleep inertia effects

A major concern around napping at night is the effect of sleep inertia upon awakening (Jewett *et al*., 1999; Tassi and Muzet, 2000; Van Dongen *et al*., 2001; Lovato *et al*., 2009; Kubo *et al*., 2010; Tremaine *et al*., 2010; Signal *et al.*, 2012; Mulrine *et al*., 2012). Although sleep inertia and its time course were not a central focus in this thesis, its consideration was warranted due to the length of the naps and their timing. The initial focus will be on the outcome measures that were sensitive to the effects of sleep inertia. Thereafter any sleep inertia effects that changed over the four night shifts or that differed between the two napping conditions are discussed.

Analyses of the pre and post nap tests revealed that only some of variables showed effects of sleep inertia, in that responses reflected a decrement upon awakening irrespective of condition. Reductions in performance were found for choice reaction time, processing speeds for the object recognition tests and simple reaction time (Figure 61, p149; Figure 64, p152; Figure 65, p152; Figure 66, p153 respectively). This was accompanied by a reduction in tympanic temperature (Figure 69, p156) post nap. The reduction in body temperature is an important precursor for sleep initiation that results from increasing blood flow and heat loss to the periphery (Dijk and Cajochen, 1997). In the current study, temperature measures were already decreasing during the course of the night shift under the influence of the circadian clock. With the initiation of sleep, thermal down regulation continued. Due to the fact that participants were awoken after only three hours and 20 minutes, the effects of this thermal down regulation were likely still in effect. According to Dinges (1990), the effects of sleep inertia manifest as a result of thermal down regulation that occurs during sleep. This in turn reduces cerebral activity, which ultimately may have contributed to performance decrements in relatively simple tasks that require basic attention, minimal decision making and response execution such as those described above. Although the current study had no insights into this, it is possible that this could account for the decrements in the processing speed, decision making and measures of basic attention. The current results also support the assertions by Tassi and Muzet (2000), in that simpler tests were more sensitive to sleep inertia than more demanding tests.

Heart rate responses were significantly higher following the nap (Figure 70, p157), while heart rate variability was significantly lower (Figure 71, p157). There are two possible reasons for these observations, as they did not correspond with the decreased temperature measures. Firstly, once the participants were awakened, each had the opportunity to visit the bathroom and to return the resting areas to consume any food they had ordered prior to napping. The physical activity, combined with the ingestion of food may have resulted in higher heart rate responses and decreased heart rate variability. A second possible reason could be the fact that, during the post nap test battery, participants were experiencing sleep inertia (as evidenced by changes in some measures discussed previously). In order to compensate for the general reduction in arousal, participants in both nap groups may have invested more effort during the test completion. Previous research has found that an increase in mental effort was associated with decreased heart rate variability measures (Aasman *et al*., 1987; Veltman and Gaillard, 1996).

5.1.4.3.1 Other effects following pre-post nap comparison

Over the course of the four shifts, processing speed during the low resolution object recognition test decreased significantly (Figure 64, p152). This reduction in processing speed could indicate increasing difficulties in reading the text as a result of sleep inertia. Alternatively, participants in both nap groups may have focused more on identifying the errors in the text than processing the text rapidly. This is supported by the fact that the errors identified during this test improved significantly over the four days (Figure 67, p154). This in accordance with the observations made by Naitoh and Angus (1987), who found that performance speed was more sensitive to sleep inertia than accuracy. The increase in motor programming time over the four shifts is likely explained by the differing response times recorded for the predictable and unpredictable targets, discussed in the Cumulative fatigue section earlier. Lastly, the significant reduction in the percentage of errors overlooked in the visual detection test (40) may also be explained by the learning effect observed in this test which was discussed earlier (Figure 63, p150).

There were some differences observed between the two nap conditions following the pre post nap comparison. For both the high and low resolution object recognition tests, the errors identified were significantly higher for the participants in the *Nap late* condition than those in the *Nap early* group (Figure 67, p154). This could possibly be attributed to the fact that the *Nap late* participants awoke from the nap at 07h40, a time of day which would favour alertness from a circadian perspective. In contrast, the *Nap early* participants awoke around the nadir, which may have negatively affected their ability identify the errors in both object recognition tests.

Contrary to this, the percentage of stimuli overlooked in the more difficult visual detection test tended to be lower following the sleep opportunity in the *Nap early* condition, compared to the *Nap late* group whose performance remained rather consistent either side of the nap (Figure 63, p150). Despite this, numerically, the percentage of errors identified was consistently higher in the *Nap early group.* This is a possible indication that the nap opportunity was more beneficial (in terms of its alerting effects) to the *Nap early* condition than to the *Nap late* condition. With respect to the memory test, performance was significantly higher in the *Nap early* group, when compared to the *Nap late* condition (Figure 68, p155). This finding is consistent with the general condition effects (discussed earlier) which highlighted that the *Nap late* condition's memory performance was generally lower than that of all the other conditions, including the *Nap early* condition.

Although pre-post nap tests for beading performance were not possible as a matter of fact, output did decrease significantly over time in all the conditions, but the profile for this decrease differed between the conditions over the course of each shift (*Condition by time effect: p<0.01*: Figure 24, p115). With respect to the *Fixed night* condition, an immediate drop in beading output between work periods one and two was observed. Thereafter output stabilised. A similar drop was evident in the *Nap early* condition, most notably after the nap opportunity. This reduction is likely due to the effects of sleep inertia, which previous studies have found to be most pronounced when waking occurs during or around the nadir of body temperature (between 03h00 and 06h00). In performing a monotonous task, the presence of sleep inertia would have accentuated disengagement from the task or possibly reduced motivation to continue performing, which supports the conclusions of Tremaine *et al*. (2010).

In contrast, during the *Nap late* condition, the output of which was the lowest compared to all conditions, the effects of the nap were less pronounced that that observed in the *Nap early*. This was possibly due to the time this group woke up and the alerting effects of both exogenous and endogenous processes at that time. Furthermore, the participants in the *Nap late* group perceived to have slept significantly longer and better than the *Nap early* participants, which may also account for the less pronounced sleep inertia. Performance did continue to decrease towards the end of shift in the *Nap late* group, possibly due to the effects of reduced motivation or disengagement from the task: this group spent the final four hours in the laboratory alone, which may have contributed to this, along with the monotony of the task.

5.1.5 Statistically non-significant results: possible explanations

In most of the performance measures included in the current investigation, responses did not reflect any effects of the conditions generally, despite a large proportion of these measures being affected by time of day and cumulative fatigue effects (as discussed in the Time of day effects and Cumulative fatigue effects section above). These included simple reaction time, accommodation time, motor programming time, high and low precision response time (during the tapping test), continuous tracking reaction time, processing speed during the object recognition tests and reaction time and percentage overlooked during both difficulties of the visual detection tests. From these results, the abovementioned measures were unaffected by the different shift regimes. This is likely attributable to the fact that these tests required the participants to perform maximally for a rather short duration. This possibly indicates that, despite participants experiencing increasing sleep pressure, circadian-modulated decrements in arousal and increased subjective sleepiness ratings, participants in all conditions were able to concentrate long enough to limit any significant performance decrements. These results could also be explained by the fact that, despite the majority of the abovementioned measures responding to time of day effects, the experimental conditions in this study appear to be ineffective in reducing the extent of these decrements.

Although these results highlight that none of the interventions were successful in reducing the fatigue effects in these particular measures when compared to what would be considered a standard night shift arrangement (the *Fixed night* condition), these observations can also be perceived in a positive light. More specifically, the effects of including an extended nap opportunity, either from 00h00 to 04h00 or 04h00 to 08h00 or a gradual rotation into the night shift generally does not differ from the effects that operating under a normal night shift arrangement would elicit.

Obtaining sleep at the right time of the day, as the participants in the nap conditions would have done, while also limiting the total time spent working during the night shift hours, are considered as important ways to effectively manage of night shift work effects. This section will deal with unpacking the potential reasons as to why the naps and the *Rolling rotation* in this context did not elicit more effects than they did. The discussion will focus initially on the effects of the *Nap early* and *Nap late* conditions, in comparison to the other conditions, before a comparison is made between the *Rolling rotation* group and *Fixed night* condition is made.

5.1.5.1 Elongated napping in comparison to the Fixed night shift and Rolling rotation conditions

In this study, it was determined that the total amount of sleep obtained during the night shifts in all conditions was much the same, when the perceived nap durations were considered along with reported sleep outside of the laboratory (Table 39, p160). While previous research has emphasised the limitations of relying on perceived sleep quality and length data (Pilcher *et al*., 2005), due to purposeful, accidental or unconscious recording of inaccurate perceptions, such measures provide important insights into an individual’s self-assessment of state and how this may impact future attitudes and behaviours (Annett, 2002) and possibly performance. According to Mollicone *et al*., (2008), MacDonald *et* al. (2013) and later Jackson *et al*. (2014) and Belenky *et al*., (2015) the fact that total sleep obtained across conditions did not differ statistically during the night shift phase could explain why average performance, irrespective of time and day differences, was similar for all conditions. These authors hold that performance is determined by the total amount of sleep obtained per 24 hours, independent of whether it is consolidated or split. However, these authors used average performance, which is not indicative of the variability of performance that may occur during a shift. Sources of such variability include the effect of time of day, as well as interventions that involve napping and any subsequent effects of sleep inertia that may follow.

A further consideration relates to the design of both napping conditions. The napping conditions were set up such that an eight-hour work shift was divided into two, shorter four work shifts, separated by an extended nap opportunity. Additionally, a 40-minute period between nap cessation and the commencement of work was implemented to allow participants to eat and complete the post nap test battery. It is this design that could account for the lack of statistically significant effects when compared to *Fixed night shift* and *Rolling rotation* conditions.

The nap opportunity in this study was 200 minutes, which would be considered to be a rather extended sleep opportunity. Although the benefits of sleep are dose dependent, in that the longer a period of sleep, the more restorative it is (Bonnet, 1991), some authors argue that it takes longer for these beneficial effects to become apparent when compared to shorter naps (Brooks and Lack, 2006; Lovato and Lack, 2010). In addition, the length of the work period after the naps in the current study may have been insufficient to allow for these benefits to become evident. This could be explained by the fact that elongated naps may be associated with extended periods of sleep inertia upon awakening (Brooks and Lack, 2006; Signal *et al*., 2012) but not always. Kubo *et al*. (2010) found that a shorter nap (60 minutes) taken at 04h00 resulted in more severe decrements than a nap 120 minutes in duration taken at the same time. A graphical representation of this (not linked the results of Kubo *et al*. 2010 or the results of this particular study) is illustrated in Figure 75.

The degree of sleep inertia is dependent upon the duration of prior wakefulness, the depth of the sleep and the circadian timing of the nap, more specifically when it ended (Dinges 1990; Tassi and Muzet, 2000; Scheer *et al*., 2008). In the current study, participants in the *Nap early* condition were awakened around the nadir. Combining this factor with the length of the nap, it is likely that this group experienced some degree of sleep inertia for the rest of the second four-hour work period. This is supported to some extent by reductions in certain performance measures and tympanic temperature, discussed in the Sleep inertia section.

In contrast, the participants in the *Nap late* condition had likely been awake for a longer period of time when compared to the other conditions, which may have resulted in a deeper sleep during the nap opportunity. This assertion is partially supported by the fact that the *Nap late* group perceived to have slept significantly longer and better than the *Nap early* condition (Figure 60, p148). Despite being wakened at 07h20, when the circadian rhythm would likely be promoting wakefulness under normal circumstances, the extended wakefulness prior to and the depth of the nap may have contributed to the presence of sleep inertia. The presence of sleep inertia was partially supported by the analyses of the pre and post nap tests, which revealed decrements in choice reaction time, processing speed during the object recognition tests and simple reaction time post nap.

Furthermore, physiologically, post nap arousal levels were significantly lower than prior to the nap, as evidenced by significantly reduced tympanic temperature. This sleep inertia may have potentially masked or delayed any benefits of the early nap on performance measures during the final four-hour work period. In the *Nap late* specifically, performance post nap may have also been affected by a reduction in motivation, as the participants were alone in the laboratory during the latter four-hour work period between 08h00 and 12h00. In contrast to both of the nap groups, during the *Fixed night* and *Rolling rotation* conditions, participants remained awake for the duration of each of the eight hour shifts, over and above a reduction in sleep length when compared to pre data collection and night time sleep. From this, it is possible that the concomitant effects of increasing sleep need, the reductions in arousal and the effects of cumulative sleep deficits elicited a similar effect on performance when compared to the two nap conditions.

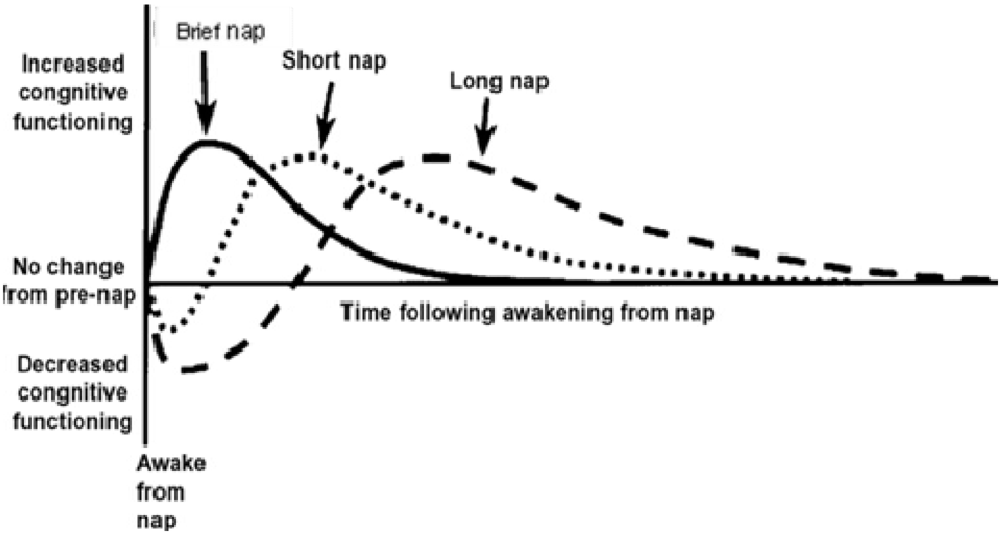

Figure 75: Graphical representation of the effects of nap length on cognitive performance upon awakening (taken from Lovato and Lack, 2010).

The observations pertaining to the effects of the extended nap opportunities on subsequent performance have implications for work contexts in which they are permitted. Future research should take cognisance of the fact that extended napping, particularly during the night, may result in a delayed manifestation of the benefits of the nap. Prior to this, performance could be compromised, which could have catastrophic effects if inappropriate or delayed decisions are made in emergency situations. As such, additional measures to increase alertness post nap, such as caffeine, should be implemented (Van Dongen *et al*., 2001). These authors reported that caffeine significantly reduced the effects of sleep inertia on psychomotor vigilance task performance. This was attributed to caffeine's antagonism of adenosine receptors in the brain (Adenosine is hypothesised to be one of the mechanisms that drive the homeostatic drive for sleep: Van Dongen *et al*., 2001).

5.1.5.1.1 Dissociation between subjective and performance responses

In addition to these observations, there was also evidence of dissociation between the subjective and objective performance measures. The question of whether subjective perceptions of sleepiness are correlated with objective performance measures has been studied with conflicting results (Sallinen *et al.,* 1998; Purnell *et al.,* 2002; Tremaine *et al*., 2010; Kubo *et* al., 2010; Zhou *et al*., 2012). In the current study, despite the perceptions of sleepiness being significantly reduced in both nap groups after the naps, very few, if any of the performance measures mirrored this trend.

This discord can be explained in a number of ways: the first possibility for this observation is the effects of the extended nature (200 minutes) of the napping opportunities. Studies that have employed naps shorter than an hour in length have mostly reported on the benefit of the nap for performance, but not always for subjective sleepiness of fatigue (eg: Rosekind *et al*., 1994b; Purnell *et al*., 2002). In contrast, naps longer than an hour tend to be perceived as more recuperative but interfere with or even reduce performance, as was the case in the current investigation. Conclusions drawn from these observations attribute the mismatch to sleep inertia, which is more pronounced following an extended nap than a shorter one.

In contrast, Kubo *et al*. (2010) reported that the presence of sleep inertia was evident following a 60-minute nap taken at 04h00, but not during a 60 min nap at 00h00 or 120 min naps taken at both times. In line with Dinges (1990) and Jewett *et al*. (1997), these authors postulate sleep inertia that may interfere with an individual’s ability to rate their sleepiness. In the study by Kubo *et al*. (2010) this was evidenced by the dissociation between VAS-determined subjective sleepiness and reaction time measures which deteriorated post nap. Jewett *et al*. (1997) found that the effects of sleep inertia decreased sooner when compared to its effects on cognitive throughput. However, the degree of sleep inertia is also dependent upon the extent of prior wakefulness prior to napping and the actual circadian timing of the nap, the wake up time and the stage of sleep during which waking occurs.

In sum, the findings of this study support those of others in that the inclusion of a nap (and in this case, an elongated one) may have interfered with an individual’s self-assessment of their perceived ability to perform. Although peripheral to the central question, this observation emphasises the importance of not only considering subjective perceptions of fatigue, as these may not necessarily always correlate with objective measures, as found in previous research (Rosekind *et al*., 1994; Tremaine *et al*., 2010; Kubo *et al*., 2010; Williamson and Friswell, 2011).

5.1.5.2 Rolling rotation vs Fixed Night condition

With respect to the *Rolling rotation*, there was limited evidence to support the benefits of the gradual introduction to the night shift. This is underpinned by the fact there were no significant differences between the *Rolling rotation* and the *Fixed night* conditions in any of the performance or physiological measures. Therefore, it appears as though the *Rolling rotation* merely delayed the inevitable decrements in performance that accompany entering the night shift.

An explanation for the lack of observed differences could be accounted for from a theoretical perspective. Under normal conditions, the circadian rhythm is entrained to the night and day cycle and the concomitant interaction with sleep homeostatic process ensures consolidated periods of sleep at the correct time of the day. When this rhythm is desychnronised, as would be the case with entering the night shift, physiological stress ensues.

After the abrupt alteration, physiological mechanisms regulate to reach equilibrium/homeostasis as fast as possible. In the case of night shift work, this would refer to the process of adapting to night shift conditions, as far as this is possible (Folkard, 2008). In the *Fixed night* condition, which was comprised of four night shifts that occurred at the same times each day, it was likely that participants began to adapt to or at the very least, “get used to” these conditions. Four consecutive night shifts have been evidenced as sufficient to facilitate partial circadian adaptation in laboratory (Roach *et al*., 2001; Lamond *et al*., 2003; Lamond *et al*., 2004) and real word settings (Bjorvatn *et al.,* 2006). This adaptation was associated improvements in sleep and performance measures. The consistency in start and end times of each shifts, as well as the light and food exposure in these studies and the current one may have contributed to some degree of adaptation or habituation in the *Fixed night* condition.

In contrast, in the *Rolling rotation* group, the “goal posts” were effectively changed for three out of the four shifts that were completed. Although the theory behind the *Rolling rotation* held that this gradual introduction would lessen the stress of entering the night shift, the method adopted to do this would have limited the chance for some degree of circadian adaptation to occur. This is due to the fact that food and light exposure and the sleeping opportunities changed for the *Rolling* group each day.

This intervention therefore did not appear to alter the negative effects of entering the night shift, illustrated in the measures of subjective sleepiness (Figure 59, p146) and post shift reported sleep (Figure 72: p159). Subjective sleepiness ratings were significantly lower in the *Rolling rotation* during the second shift (*Fixed night* group's first night shift), but this was mainly attributable to the differences in working time and time awake between the two conditions. Over the next two shifts, sleepiness increased significantly as the *Rolling rotation* group entered the real night shift (22h00 to 06h00). This was accompanied by a reduction in reported sleep length leading up to the first proper night shift as well (Figure 72, p159).

The gradual increase in sleep loss in the *Rolling rotation* condition over the shift period could account for why there were no clear differences with respect to *Fixed night* condition. This group (the *Fixed night*) demonstrated a trend towards improved sleep length over the four shifts, which further supports the assertion that partial circadian adaptation may have started to occur. These findings support the contentions made by Pilcher *et al*. (2000) that shift rotations that occur slowly (after five consecutive days) result in improved sleep length, relative to those that rotate rapidly (every 1 to 3 days) of which the *Rolling rotation* group could be considered part of.

CHAPTER 6: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY OF KEY FINDINGS OF THIS STUDY

The initial analyses focused on validating the sensitivity of the dependent variables selected to study the effects of simulated night work. In this study, the simulated night shifts resulted in reduced beading output and compromised performance in some of the simple visual perception and psychomotor tests during the four night shifts. Tasks that required more attention and cognitive effort demonstrated a significant time effect, but only during the final two night shifts. Most of the physiological measures were also sensitive to time effects, and reflected a decreased arousal during the night shifts. This could partially explain the decrements in the performance measures, which were also accompanied by increased subjective sleepiness over the course of each night shift.

Despite the majority of the performance, cognitive, physiological and subjective measures demonstrating fatigue effects over time, very few responses changed over the course of the four night shifts. The exception was the self-paced beading task, which showed decrements in output over the last three night shifts. This was accompanied by a reduction in reported sleep length outside of the laboratory, specifically with the start of the night shift phase. Apart from these, some visual perceptual, cognitive and psychomotor measures showed consistent improvements over the course of the four night shifts, which were likely reflective of learning effects.

Neither the gradual rotation, nor the provision of extended napping opportunities yielded many significant differences, when compared to the *Fixed night* condition. Beading performance was markedly higher in the *Rolling rotation* condition, when compared to the *Nap late* group. The *Nap late* condition also performed significantly worse in both working memory tests, relative to the other conditions. While the perceived sleep length and quality during the nap opportunity was significantly higher in the *Nap late* condition, relative to the *Nap early* group, both nap conditions' reported sleep length outside of the laboratory was significantly shorter when compared to the *Rolling and Fixed night* conditions. When reported nap sleep length was added to sleep length outside the laboratory, there were no significant differences between all conditions.

There was some evidence of sleep inertia following the nap in both *Nap early* and *Nap late* conditions. Napping was associated with reductions in temperature measures and immediate reductions in certain visual perceptual measures post nap. These were accompanied by increased measures of heart rate frequency and decreased heart rate variability. However, after both naps, subjective sleepiness was also reduced relative to the other conditions. This result highlighted the dissociation between subjective and objective measures, where despite feeling alert following the naps, performance measures did not reflect this. Over the four night shifts, the gradual introduction to the night shift also resulted in increasing subjective sleepiness. In the *Fixed night* condition and nap conditions, ratings remained relatively consistent.

6.1.1 Response to hypotheses

The research hypothesis proposed that the simulated night shift conditions would be associated with fluctuations in performance, physiological arousal and subjective sleepiness. In addition, it was hypothesised that these effects would be accentuated over the remaining shifts, irrespective of condition. Furthermore, it was proposed that the inclusion of the three experimental interventions, relative to the *Fixed night* condition would result in differential effects in the measured outcomes generally, over the course of each shift and over the four night shifts.

6.1.1.1 Hypothesis 1: Time of day effects

This study tested the hypothesis that working the night shift would not alter the performance, physiological and subjective outcome measures included, irrespective of condition generally and during the final two shifts:

HO: μMeas(Time1)= μMeas(Time2)= μMeas(Time3)…..=μMeas(Time6)

The Null hypothesis is tentatively rejected for measures of beading output, simple reaction time, motor programming time, high precision response time, high resolution processing speed and pattern recognition, the percentage overlooked during visual detection test (40), tympanic temperature, heart rate frequency, r-MSSD and subjective sleepiness measures. With respect to the final two shifts, the Null hypothesis is rejected for all of the above (except high precision response time) and the percentage recalled during both difficulties of the working memory test, low resolution processing speed and pattern recognition and the percentage overlooked in the visual detection test (80).

6.1.1.2 Hypothesis 2: Day / cumulative effects

A second focus was on testing the hypothesis that performance, physiological, subjective and sleep measures would not differ over the four night shifts that were tested:

$$\textbf{HO: } \mu\text{Meas(Night 1)} = \mu\text{Meas(Night 2)} = \mu\text{Meas(Night 3)} = \mu\text{Meas(Night 4)}$$

The Null is tentatively rejected for beading output, the percentage recalled during the working memory test with short recall delay, motor programming time, reaction time during both the high and low sensitivity tracking tests, reaction times and the percentage overlooked in both difficulties of the visual detection test as well as reported sleep length and quality obtained following the first night shift, relative to the afternoon shift.

6.1.1.3 Hypothesis 3: General condition effects

The hypothesis that a gradual introduction to the first night shift and an extended nap opportunity combined with a split shift would not evoke any significant changes in all the measured outcomes generally over the four night shifts, relative to the *Fixed night* condition, was proposed:

$$\textbf{HO: } \mu\text{Meas.(Cond.)}_{FN} = \mu\text{Meas.(Cond.)}_{RR} = \text{Meas.(Cond.)}_{NE} = \text{Meas.(Cond.)}_{NL}$$

Beading output was significantly higher in the *Rolling rotation* condition when compared to the *Nap late* group. The naps in both the *Nap early* and *Nap late* conditions also reduced reported sleep length post shift over the testing phase relative to the *Fixed night* and *Rolling rotation* conditions. Moreover, memory performance was significantly lower in the *Nap late* condition when compared to the *Fixed night* and the *Nap early* conditions. The *Nap late* condition reported significantly longer and better quality sleep during the nap, relative to the *Nap early* condition. As such, the null is rejected for these variables only and the alternate hypothesis is tentatively accepted.

6.1.1.4 Hypothesis 4: Condition and time of day interaction

The penultimate hypothesis proposed that the addition of the *Rolling rotation* and naps interventions, compared to the *Fixed night* condition would not significantly alter the effects of the circadian, homeostatic and time-on-task influences on the response outcomes over time:

The null hypothesis is tentatively rejected for the measures of beading output, choice reaction time, reaction time for visual detection test (80 distractors), tympanic temperature, heart rate, r-MSSD and subjective sleepiness measures, which were significantly altered by the inclusion of the nap interventions, relative to the *Fixed night* and *Rolling rotation* conditions.

6.1.1.5 Hypothesis 5: Condition and day interaction

The final hypothesis was related to the effect that the *Rolling rotation* and nap interventions would have on outcome measures over the course of the four night shifts, in that the interventions would not result in any changes in the outcomes during this phase:

Measures of reported sleep length during the actual night shift were significantly lower in both nap groups, relative to the *Fixed night* and *Rolling rotation* conditions. Furthermore, reported post shift sleep length decreased in the *Rolling rotation* condition, while staying relatively stable in the *Fixed night* group. With respect to the subjective sleepiness measures, the *Rolling rotation* condition resulted in a gradual increase in sleepiness ratings as the gradual rotation occurred, relative to the other conditions. The null hypothesis is therefore rejected tentatively for these responses.

6.2 CONCLUSIONS

This study confirmed that night shift work in a simulated setting (irrespective of the experimental conditions) is strongly associated with a reduction in physiological arousal associated with the time of day at which participants were awake. The reduction in physiological arousal coupled with increasing sleep pressure and time on task effects were associated with, but did not necessarily cause decrements in a number of stages of human information processing. These included participants' ability to remain vigilant and attentive (all tests), process information (object recognition tests) visually perceive and recognise patterns or key stimuli (simple reaction time, visual detection tests and object recognition tests), working memory, motor response and control measures (tapping tests). In addition to performance changes, subjective perceptions of sleepiness increased relatively linearly throughout each night shift.

Eye accommodation time, basic decision making (tested via a choice reaction time task), tracking performance (motor control) and vigilance reaction time were not negatively affected by or sensitive to the night shift conditions. In short the conditions associated with night work negatively affect most processes in the human information processing chain in some way. These findings also highlight, to some extent, the validity of certain measures included in this study to measuring circadian and homeostatic influences. More research to further validate them is however necessary.

There was some evidence of cumulative fatigue in the current study. Entering the night shift was associated with significant reductions in post shift recovery sleep, which remained shorter than reported night sleep length (following the first afternoon shift) for the remainder of the data collection. This was accompanied by a significant reduction in beading output, a self-paced, monotonous task which required the participants to focus for extended periods of time. In contrast, learning effects associated with the repetitive testing procedures were evident in responses during both difficulties of the visual detection and continuous tracking tests, as well as the working memory test with the shorter delay. Apart from these measures, there was no other evidence of cumulative fatigue or adaptation effects associated with this simulated night shift set up. From these results, it appears that extended, self-paced, monotonous tasks are more sensitive to cumulative fatigue than externally-paced, short duration tests.

This study explored the concept of a gradual introduction to the night shift, facilitated through the *Rolling rotation* intervention. This progressive introduction into the night shift resulted in the highest beading output of all the conditions, but this was only statistically significant with reference to the *Nap Late* condition. Apart from this result, the *Rolling rotation* intervention appeared to merely delay the inevitable reductions in physiological arousal, cognitive performance and subjective sleepiness, which in most cases, matched that of the *Fixed night* condition over the four night shifts and the final two shifts of the data collection. It can be therefore concluded that the effectiveness of this intervention in the current thesis was limited in comparison to *Fixed night* and the nap conditions. However, the responses observed in *Rolling rotation* were no worse than those of the other conditions.

In addition to the *Rolling rotation* intervention, this study investigated the efficacy of a staggered, split shift nap combination in the context of regular eight hour shifts. The extended nap opportunities significantly reduced subjective sleepiness in both the *Nap late* and *Nap early* conditions, relative to *Fixed night* and *Rolling rotation* conditions, but only after the nap. In the *Nap late* condition specifically, this was accompanied by an increase in physiological arousal, which could be attributed to the time of day at which this group awoke and not the effects of the nap exclusively. Despite this positive observation, the findings of this study support previous research in that the time that a night shift starts has a fundamental impact on initial and subsequent worker alertness and performance. This was demonstrated by the significantly reduced beading output in the *Nap late* condition, relative to the *Rolling rotation* group. In addition, working memory was negatively affected by the late shift start time in the *Nap late* condition in both difficulties of the working memory test, relative to the other conditions. As such, from a broader perspective, these results highlight and support that fact that late starts to night shifts should be avoided.

The inclusion of an elongated napping opportunity, irrespective of its timing, resulted in a significantly reduced post shift recovery sleep, relative to the *Fixed night* and *Rolling rotation* conditions. This is a common finding in napping intervention research. However, combining the perceived nap time with the reported post shift recovery sleep negated the differences between all the conditions. This outcome, that total sleep obtained per 24 hours was similar for all conditions despite the biphasic nature of that obtained during the nap conditions, could account for the minimal differences in performance outcomes between all the conditions. Previous research has emphasised that the total amount of sleep obtained per day, not necessarily how it is obtained (consolidated or split) determines the average level of performance. Having said this, it is unrealistic and somewhat ill advisable to not consider the more immediate effects of the nap conditions and the effects these had on overall performance capacity. This refers specifically to the effects of sleep inertia post nap.

The inclusion of an extended napping opportunity resulted in sleep inertia in both nap groups which negatively affected visual perception tests mostly (simple and choice reaction time and processing speed) 20 minutes after participants awakened from the nap. Despite this observation, the design of this study, specifically the spacing of the test batteries, did not facilitate detailed insights into the time course of sleep inertia. The lack of significant effects however suggested that the presence of sleep inertia or remnants of its effects is another likely explanation why the majority of the performance measures did not differ between the napping conditions and the other two conditions. It is likely that the dose dependent effects of the lengthy nap did not have enough time to manifest in the second four hours of each shift. This has implications for medical, aviation, maritime and railway industry personnel who may have the opportunity to nap for extended periods of time during the night shift. Additional measures to reduce the potential impact of sleep inertia post nap are recommended.

Apart from some of these immediate negative effects, the split shift nap intervention in this study may provide an alternative to staying awake for an entire night shift (as was the case in the *Fixed night* and *Rolling rotation* conditions). This supports the application of elongated napping in contexts where extended shifts are practised, with a cautionary statement that additional measures to combat sleep inertia effects are considered.

6.2.1 Reflections and recommendations

6.2.1.1 Methodological recommendations

As opposed to solely providing an overview of the methodological approach used in the current study, this section includes a critical reflection on the limitations of this study with respect to the methodology applied. Contained within this critique are additional recommendations for future research of a similar nature, which will supplement the broader research recommendations and outlook made at the end of this chapter.

6.2.1.1.1 Data collection logistics

The data collection of all 45 participants had to span over two, separate five-day sessions (24 participants in each) owing to the limited laboratory space and equipment availability. The first data collection period occurred during September 2012 and the second during April 2013. These two months were chosen as the seasonal light levels over these periods are fairly similar; differences in environmental light levels would have had an impact and were therefore controlled as much as was possible. Furthermore, the venue for the April data collection period had to change due to September venue not being available. However, the test battery and working areas were set up in the same way in both venues and the lighting levels, the food menu and the napping conditions were made as similar as possible. Although this was not an ideal scenario, all steps were taken to ensure that the two different environments were as similar as possible.

6.2.1.1.2 Design of the experimental conditions

The study adopted an independent groups design, measured repeatedly over time. Although a repeated measures design may have been preferable, the nature of the testing would have required participants to be involved for extended periods of time, which was unrealistic and would probably have been associated with habituation effects. In experimental designs such as this, it is recommended that more participants be recruited to increase the statistical power of a study

The study also focused exclusively on the effects of the different conditions during the initial and subsequent night shifts, without considering the impact that these experimental conditions would have on morning or afternoon shift arrangements and responses therein. As such, the different arrangements' applicability / practicality / efficacy in real world contexts may be limited.

In addition, and with specific reference to the design of the conditions, the fact that in most cases, the shift times were not similar made the comparison of the responses obtained in the various outcome measures difficult. This is due mainly to the differences in the duration of prior wakefulness, circadian phase and homeostatic sleepiness which would result from these differences in the condition set up. Although the responses were analysed as if all conditions were scheduled at the same time, the subsequent interpretation of these results took cognisance of the differences in shift timings.

Experimental designs such as these also make it difficult to isolate and explain specific effects, but they provide important insights into the complex nature of shift system design which may not always be fully appreciated in very rigidly controlled laboratory experimentation. This is the compromise that was reached in the current study, as there was no other way of studying the effects of the different experimental conditions. Such considerations are important for future laboratory research, if real-world research is not possible or feasible.

6.2.1.1.3 Participant characteristics

In all likelihood the sample sizes in each condition were rather small, which may have negatively affected the statistical power of this study. At the completion of the data collection, the *Fixed night*, *Rolling rotation* and *Nap early* conditions were comprised of 10, 11 and 11 participants respectively, while all 12 participants completed the study as part of the *Nap late* group. The data collection required a significant investment of time on the part of the participants, and although there were some interesting findings, the inclusion of more participants or extending data collection period may have yielded more condition effects. However, as the participants were students and that the data collection had to occur during their short, week long vacations, extending the testing was not feasible.

The small sample size and its effect on the statistical power lead to the consideration of increasing the significance criterion from 0.05 to 0.1. While this may have increased the power and reduced the chance of Type 2 error, it may have also increased the chance of Type 1 error. Even without this consideration, the small sample size may have resulted in an increased risk of false positive results. As such, future studies should aim to increase the number of participants, particularly in studies that adopt an independent group comparison design such as the one used in this study.

Individual differences were not considered or analysed in this study. However, future research should consider the impact of factors such as age, sex, personality and chronotype when interpreting data. This would highlight individuals who are more tolerant and those who are less tolerant to the imposed conditions. This information will contribute to a better understanding of what factors contribute to shift work / sleep loss tolerance. Alternatively, such factors must be strictly controlled for.

With respect to the participants, young healthy students were recruited. This unfortunately limit the generalisability of these findings to the working population. Apart from the exclusionary criteria outlined in the methods section, no further medical or diagnostic tools were used to screen participants for other sleep or medical-related problems. Furthermore, although the question was asked of each of the female participants, the effects of the menstrual cycle were not strictly controlled: menses is known to alter body temperature, which may in turn affect the female participant arousal and performance levels.

Additionally, student volunteers, by their very nature, do sometimes experience irregular or delayed sleep patterns, which may predispose them to being more tolerant to simulated night shift work. Future work of this nature should also include more stringent screening of potential participants for sleep or circadian-related disorder to ensure that these do not negatively influence the results.

6.2.1.1.4 Data collection procedures

Outcome measures selected

Although the physiological and subjective measures selected for this study have previously demonstrated the effects of circadian and sleep-related disruptions from shift work, the majority of the cognitive performance measures had not been applied in such conditions. Although this contributed to the novelty of the study, these tests had been developed within the author's department and had previously not been shown to be sensitive to sleep loss or circadian disruption. Furthermore, the tests selected were not reflective of real world tasks, but merely highlighted different elements of the information processing chain that may potentially be affected by night shift conditions. This is a common pitfall outlined in both simulated and real world shift work research.

Furthermore, the current data collection likely included too many dependent variables. While the reasoning behind this revolved around trying to obtain a holistic overview of the effects night shift work on various stages of human information processing, future research should consider including fewer, more sensitive measures. This will enable a more in depth analysis of the outcome measures, from which more specific interpretations and conclusions may be drawn.

Moreover, some of the tests were subject to very evident learning effects, which was likely the result of the fact that participants completed these tests 30 times during data collection. In the case of the napping conditions, this number was closer to 40. In spite of this, these learning effects were balanced out between all conditions. While this was not anticipated, it will assist in the modification of the relevant tasks to avoid this during future research. Nevertheless, despite the lack of ecological validity of the tests along with some evidence of learning effects, the tests in this study did provide insights into some of the key cognitive processes (such as attention, reaction time, memory, decision making and motor performance) that are important for the completion of real world tasks. An understanding of how night shift work and the potential benefits of the experimental conditions affect these processes can aid in the development of context-specific countermeasures. Including more established and validated tests should be considered in research of a similar nature – this will make the comparison and interpretations of data easier. The frequency of testing under similar conditions also needs careful consideration.

In order to determine the appropriateness of tests that are not validated (as was the case in this study), a further recommendation would be to include a pilot testing phase prior to the start of the main study. This will elucidate tests that are either subject to severe learning effects or tests that are insensitive to the conditions to which they are applied. This will ensure that redundant tests are excluded, which will ultimately improve the quality of the data obtained. Additionally, baseline measurements of the participants prior to exposure to the night shift would have been useful to demonstrate how the tests responded to different times of the day and under varying degrees of sleepiness. Although this was partially achieved with the baseline afternoon shift, this particular shift served more as a familiarisation shift than a baseline session. Alternatively, a day time control group would achieve the same ends. This was not logistically possible in the current study, due to extended and staggered testing times, which limited the break opportunities for the actual research staff. Nevertheless, future studies, similar to the current one, should include a period of baseline testing or a day time control to obtain a more complete view of how certain dependent variables respond.

Test battery organisation

Prior to testing, participants spent the majority of each shift seated while performing the beading task. In both data collection venues, in order for participants to be tested, they had to stand and walk to the testing venue. This act of physically moving may have had an alerting effect, which likely influenced the responses to the outcome measures. However, all participants were exposed to the same level of activity, which ensured that the comparisons that were made between the different conditions were not compromised. The actual execution of each test battery was a logistical challenge. Each test battery taking 20 minutes to complete, which meant that there were occasions during the testing where the time between two conditions being tested was as long as 60 minutes. In addition, the order in which each condition was tested, as well as the order in which each participant completed the test battery was maintained throughout the study. Ideally, both of these factors should have been randomised in order to limit any potential order or bias effects, but the taxing nature of the testing lead the researcher to compromise on this to ensure that participants and research assistants alike were able to successfully complete each test battery at and in the appropriate time. These are important considerations for related research. Testing fewer experimental conditions in one scenario will ease such a logistical load, as will reducing the number of dependent variables.

6.2.1.1.5 Food provision

The main aim of providing regular meals, which occurred at roughly two, four and six hours during each eight-hour shift (apart from the nap conditions) was to negate the effects of hunger throughout the shifts. These snacks were provided after each group had completed their test battery and not at a set time. This prevented some groups eating right before their next test battery and others waiting nearly an hour after eating before their respective tests. It was assumed that this arrangement would mean that each condition would arrive at testing having had the same amount of time to adjust to the intake of food.

Furthermore, a limited variety and amount of food was available to the participants during the abovementioned times, but not all participants ate when offered food. Although this may have affected their alertness due to the energising effects of food intake and consequently their performance, it would have been just as unethical to force participants to eat as it would be to deprive of them of it. An additional aim of the food provision, besides limiting hunger, was to ensure that participants felt “taken care of” so that they remained part of the study, the set up for which required a lot of them (Signal *et al*., 2012). As such, the provision of food in terms of what it is, how much is provided and how frequently it is made available is important, as these factors may affect/mask participant response under night shift conditions.

6.2.1.1.6 Nap quality

Although a central component of this nap intervention relied on participants actually sleeping, the only insights gained were subjective ratings of perceived nap length and quality. Additional indicators of sleep, such as actigraphy, would provide more reliable information on sleep obtained in such scenarios.

6.2.1.1.7 Activities outside of the laboratory

Despite the habituation, during which certain restrictions for participating in the current study were explained, the researchers had no insight into and control of the activities of the participants while outside the laboratory. This stemmed mainly from participants failing to complete the relevant sections in the sleep diary that requested this information. However, in real world settings where shift work is practised, employers also have very little control over what employees do once they have left work. Furthermore, no insight into the actual length and quality of the post shift sleep was obtained, apart from the reported sleep characteristics obtained from the sleep diary. This method is also not as reliable as other methods (such as actigraphy), but provided some useful information despite this limitation.

6.2.1.1.8 Recovery effects

This study assessed the pre and data collection sleep length outside the laboratory, but not the post data collection period. This was a limitation, which may have provided interesting information about how long the participants in the different conditions may have taken to recover or re-orientate themselves back to normal hours of wakefulness and sleep. Future research should address this limitation, as it would provide more holistic insights into the effects of different shift work interventions.

6.2.2 Outlook and possible areas of future research

6.2.2.1 Rolling rotation intervention

Although limited in terms of practicality in most real world settings, the *Rolling rotation* intervention deserves further scrutiny in laboratory-based settings. Through chronobiological research, during which established circadian markers such as melatonin, cortisol and continuous core body temperature measures can be applied, a better understanding of the physiological changes that may occur as a result of this intervention can be derived, when compared to a rapid transition. Additionally, understanding how such a shift rotation system would impact on alertness and performance in other shifts, such as morning and afternoon shifts is further warranted to obtain a more holistic perspective of the effects of such an intervention.

Furthermore, the use of additional chronobiological methods to promote partial adaptation, such as light exposure, melatonin, dark glasses post shift, better control of light exposure during the day can be applied in addition to this *Rolling rotation*. This may provide further insights in how best to introduce shift workers to the night shift and whether the combination of these factors increases the effectiveness of this intervention. More generally, there is still a need to understand which characteristics of shift system design are most effective in limiting fatigue associated with shift work. This refers specifically to the number of consecutive night shifts, the speed and direction of rotation as well as the start times for different shifts, the evidence for which is still contentious. More broadly, context-specific recommendations for shift scheduling, as part of a broader fatigue risk management program, continue to be a research priority.

6.2.2.2 Split shift nap combination intervention

The findings of this study emphasise that an extended nap between two, four hour periods of work, elicited a limited benefit with respect to cognitive performance, possibly due to the benefits of the nap not having enough time to become manifest. In light of this, further research should aim to determine how long after waking from extended nap opportunities personnel are able to perform. This could be achieved by the inclusion of more sophisticated measures such as electroencephalography and polysomnography, to determine the depth of sleep obtained during such extended nap opportunities. Thereafter, changes in post nap alertness and cognitive performance should be carefully monitored to determine the time course for the dissipation of sleep inertia and / or the return to baseline or pre nap performance levels. This will also help to identify which specific elements of human information processing chain are negatively affected by sleep inertia.

Understanding these processes has implications in work contexts in which elongated naps during extended shifts are practised. Such extended shifts, which are commonplace in medical, aviation, marine and railway contexts, can be associated with extended periods of wakefulness, which can contribute to an increased depth of sleep and possible sleep inertia upon awakening. In light of this, additional research into possible countermeasures such as the use of caffeine or physical activity is imperative.

In this study, awakening in the nadir (≈04h00) was associated with partial impairments to alertness and performance, to a lesser extent than awakening nearer more conventional times (≈07h00). As such, future research should consider exploring different combinations of split shift and nap timings in order to determine which combinations would result in the most restorative sleep and the fewest challenges post wake up. Although this is an ongoing debate, the practise of napping is still held as an effective countermeasure against fatigue associated with night work, which deserves continued attention. Although peripheral to the question about napping, this study highlighted the negative impact of late starts to night shift work. Future research should potentially focus on understanding the effects of different night shift start and end times of alertness and performance before and during work periods, as well as the effects these have on either pre shift or post shift sleep for night shifts and other {morning and afternoon} shifts.

6.2.2.3 Concluding statement

The practise of shift work is likely to continue owing to need for the constant provision of emergency and health services, transport and the manufacture of goods and other services. Although the results of the current study are limited in the extent to which they can be applied to real world contexts, the magnitude of the challenges to personnel and public safety warrant the continued investigation of innovative and perhaps unconventional ways of reducing the impact of shift work in occupational settings and on society as a whole. If such studies yield promising results, the next step would be to determine how to put these into practice. Laboratory and real world shift work research can be expensive, time consuming and difficult, but very necessary. If indeed close to 20% of the world's population work some form of atypically timed work, this research and its outcomes will contribute to improving the occupational health of millions of workers and the general public globally every day.

SUPPORTING DOCUMENTATION

7.1 REFERENCES

Please note that references that are preceded by an asterisk * were secondary sources that could not be obtained directly.

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7.2 PEER REVIEWED PUBLICATIONS (UNRELATED TO THIS THESIS)

Davy, J.P. (2011). An introductory overview of the 20th International Symposium on Shift work and Working time: research opportunities for South Africa. Ergonomics SA, Vol 23, No 1. ISSN number 10 10 27 28. (URL: **http://reference.sabinet.co.za/document/EJC33299**)

Davy, J.P, & Göbel, M. (2013). The effects of a self-selected nap opportunity on psychophysiological, performance and subjective measures during a simulated industrial night shift regimen. Ergonomics, 56:2, 220-234. (URL: http://www.tandfonline.com/doi/full/10.1080/00140139.2012.751459#.U24uHl6KDDc)

Huysamen, K.C., Göbel, M. & Davy, J.P. (2013). The effects of different types of cognitive tasks in conjunction with circadian regulation on heart rate variability and performance variability. Ergonomics Journal of South Africa, 25; 1, 52-68. (URL: http://reference.sabinet.co.za/document/EJC138993)

Davy, J.P. (2014). Good sleep, good health and good performance. It's obvious. Or is it? The importance of education programmes in general fatigue management**. Ergonomics Journal of South Africa, 26; 1, 64-73. ISSN number 10 10 27 28.** (URL: **http://reference.sabinet.co.za/document/EJC157022**)

Steenekamp, T. & Davy, J. (2015). The effects of partial sleep restriction on biomechanical, physiological, and perceptual responses during an early morning treadmill run**. Journal for Community Health Sciences. (In press*).***

7.3 PEER REVIEWED PUBLICATIONS IN CONFERENCE PROCEEDINGS (Full papers) UNRELATED TO THIS THESIS

Davy, J.P., Göbel, M. & Lombard, W. (2011). A comparison between nap and booster break interventions to cope with fatigue during night shift work. Human Factors in Organisation Design and Management X Volume 1, p301-306. Grahamstown, South Africa. IEA Press. ISBN:0-9768143-4-X.

Davy, J.P., Göbel, M, & Lombard, W. (2011). Challenges of assessing the psychophysiological effects of working at night. Human Factors in Organisation Design and Management X Volume 1, p395-400. Grahamstown, South Africa. IEA Press. ISBN:0-9768143-4-X

7.4 PEER REVIEWED CONFERENCE PUBLICATIONS (Abstracts only) UNRELATED TO THIS THESIS

Davy, J.P. & Göbel, M. (2011). The effects of self-selected nap opportunity during simulated night shift work" was published in a book of abstracts as well. Paper delivered at the **20th International Symposium on Shift work and Working Time: Stockholm; Sweden**. Details are as follows: Shift work International Newsletter, SIN Volume 25. ISBN 0265-5357.

Davy, J.P. (2011). Night shift work: the current status and a critical reflection on challenges and best research practices**.** Paper delivered at the **3rd annual Interdisciplinary Postgraduate Conference; Rhodes University**.

7.5 PEER REVIEWED CONFERENCE PUBLICATIONS (Abstracts only) RELATED TO THIS THESIS

Davy, J.P. & Göbel, M. (2013). Warming up to the night; exploring a novel shift system design to ease the transition into night shift work. Paper delivered at the **5th annual Interdisciplinary Postgraduate Conference; Rhodes University.**

Davy, J.P. & Göbel, M. (2014). Napping and a staggered, “tag-team” shift system design as a means of combating the difficulties associated with working the night shift. Paper delivered at the **1st South African Symposium on Human Factors and Aviation; Johannesburg; South Africa**.

Davy, J.P. & Göbel, M. (2014). An overview of the circadian and shift work-related research in the Department of Human Kinetics and Ergonomics at Rhodes University. Paper delivered at the **Airwaves Conference: a meeting of the South African Sleep Medicine Association: Durban, South Africa.**

Davy, J.P. & Göbel, M. (2014). Innovative shift ergonomics interventions to reduce the performance decrements associated with night shift work; a laboratory-based investigation. **Paper delivered at the 5th International Conference on Applied Human Factors and Ergonomics, Krakow, Poland.**

7.6 DETAILED BREAKDOWN OF CONDITION ARRANGEMENTS

NE = Nap early, NL = Nap late, RL = Rolling rotation, FN = Fixed night

TIME OF DAY	SHIFT 1	SHIFT 2	SHIFT 3	SHIFT 4	SHIFT 5
13H00 - 13H20	NE PRE TEST				
13H20 - 13H40	NL PRE TEST				
13H40 - 14H00	FN PRE TEST				
14h00 - 14h20					
14h20 - 14h40	NE TEST 1				
14H40 - 15H00	NL TEST 1				
15H00 - 15H20	FN TEST 1				
15h20 - 15h40					
15h40 - 16h00	RL PRE TEST / BREAK (NE, NL, FN)				
16h00 - 16h20					
16H20 - 16H40	NE TEST 2				
16h40 - 17h00	NL TEST 2				
17h00 - 17h20	FN TEST 2				
17h20 - 17h40	RL TEST 1				
17h40 - 18h00	BREAK ALL CONDITIONS	RL PRE TEST			
18h00 - 18h20					
18h20 - 18h40	NE TEST 3				
18h40 - 19h00	NL TEST 3	RL TEST 1			
19h00 - 19h20	FN TEST 3				
19h20 - 19h40	RL TEST 2				
19h40 - 20h00	BREAK ALL CONDITIONS	RL BREAK	RL PRE TEST		
20h00 - 20h20		NE PRE TEST	NE PRE TEST	NE PRE TEST	NE PRE TEST
20h20 - 20h40	NE TEST 4				
20h40 - 21h00	NL TEST 4	RL TEST 2	RL TEST 1		
21h00 - 21h20	FN TEST 4	NE TEST 1	NE TEST 1	NE TEST 1	NE TEST 1
21h20 - 21h40	RL TEST 3	FN PRE TEST	FN PRE TEST	FN PRE TEST	FN PRE TEST
21h40 - 22h00	BREAK RL ONLY	BREAK RL & NE	BREAK RL & NE	BREAK NE / RL PRE TEST	BREAK NE / RL PRE TEST
22h00 - 22h20	NE POST TEST				
22h20 - 22h40	NL POST TEST				
22h40 - 23h00	FN POST TEST	RL TEST 3	RL TEST 2	RL TEST 1	RL TEST 1
23h00 - 23h20		NE TEST 2	NE TEST 2	NE TEST 2	NE TEST 2
23h20 - 23h40	RL TEST 4	FN TEST 1	FN TEST 1	FN TEST 1	FN TEST 1
23h40 - 00h00		NL PRE TEST/BREAK RL FN	NL PRE TEST/BREAK RL FN	NL PRE TEST/BREAK RL FN	NL PRE TEST/BREAK RL FN
00h00 - 00h20	RL POST	NE PRE NAP TEST	NE PRE NAP TEST	NE PRE NAP TEST	NE PRE NAP TEST
00H20 - 00H40					
00H40 - 01H00		RL TEST 4	RL TEST 3	RL TEST 2	RL TEST 2
01H00 - 01H20		NL TEST 1	NL TEST 1	NL TEST 1	NL TEST 1
01H20 - 01H40		FN TEST 2	FN TEST 2	FN TEST 2	FN TEST 2
01H40 - 02H00		BREAK FN AND NE	BREAK FN AND NE	BREAK FN, NE AND RL	BREAK FN, NE AND RL
02H00 - 02H20		RL POST TEST	RL TEST 4	RL TEST 3	RL TEST 3
02H20 - 02H40					
02H40 - 03H00		NL TEST 2	NL TEST 2	NL TEST 2	NL TEST 2
03H00 - 03H20		FN TEST 3	FN TEST 3	FN TEST 3	FN TEST 3
03H20 - 03H40		BREAK FN	BREAK FN	BREAK FN AND RL	BREAK FN AND RL
03H40 - 04H00		NL PRENAP TEST / NE WAKE	NL PRENAP TEST / NE WAKE	NL PRENAP TEST / NE WAKE	NL PRENAP TEST / NE WAKE
04H00 - 04H20		NE POST NAP TEST	NE POST NAP TEST	NE POST NAP TEST	NE POST NAP TEST
04H20 -04H40			RL POST TEST	RL TEST 4	RL TEST 4
04H40 - 05H00		FN TEST 4	FN TEST 4	FN TEST 4	FN TEST 4
05H00 - 05H20		NE TEST 3	NE TEST 3	NE TEST 3	NE TEST 3
05H20 - 05H40					
05H40 - 06H00		BREAK NE	BREAK NE	BREAK NE	BREAK NE
06H00 - 06H20				RL POST TEST	RL POST TEST
06H20 - 06H40		FN POST TEST	FN POST TEST	FN POST TEST	FN POST TEST
06H40 - 07H00					
07H00 - 07H20		NE TEST 4	NE TEST 4	NE TEST 4	NE TEST 4
07H20 - 07H40		NL WAKE	NL WAKE	NL WAKE	NL WAKE
07H40 - 08H00		NL POST NAP TEST	NL POST NAP TEST	NL POST NAP TEST	NL POST NAP TEST
08H00 - 08H20					
08H20 - 08H40		NE POST TEST	NE POST TEST	NE POST TEST	NE POST TEST
08H40 - 09H00		NL TEST 3	NL TEST 3	NL TEST 3	NL TEST 3
09H00 - 09H20					
09H20 - 09H40					
09H40 - 10H00		BREAK NL	BREAK NL	BREAK NL	BREAK NL
10H00 - 10H20					
10H20 - 10H40					
10H40 - 11H00		NL TEST 4	NL TEST 4	NL TEST 4	NL TEST 4
11H20 - 11H40					
11H40 - 12H00					
12H00 - 12H20		NL POST TEST	NL POST TEST	NL POST TEST	NL POST TEST

7.7 RECRUITMENT ADVERTISEMENT

ATTENTION ALL RHODES STUDENTS AND COMMUNITY MEMBERS

OPPORTUNITY TO TAKE PART IN DOCTORAL SHIFT WORK RESEARCH: SEPTEMBER 9TH TO 15TH 2012

The Department of Human Kinetics and Ergonomics invites interested students and community members to participate in a Doctoral research project on the hardships associated with **NIGHT SHIFT WORK.** This will be phase one, in which we will require 24 participants.

DATES: 9TH – 15TH of September 2012

WHERE: Biopharmaceutics Research Institute Laboratory (above House Keeping Headquarters)

INCLUSION CRITERIA: in order to participate, interested individuals should meet the following criteria:

- **Males and females, aged between 18 and 28 years**
- **Non-smokers**
- **No prior shift work experience**
- **No transmeridian travel (flights across more than 2 time zones) in the last 2 months**
- **No sleep-related disorders (sleep apnoea, obstructive sleep disorder, insomnia)**
- **No regular consumption of alerting medication**
- **No regular consumption of sleep promoting medication such as melatonin or sleeping pills**
- **Good physical health**
- **Regular sleeping patterns (at least 7 to 8 hours of sleep a night)**

STUDY LENGTH: 5 consecutive, 8 hour shifts; one afternoon shift and four night shifts. These will be preceded by an introductory session and one habituation session.

BENEFITS: Interested participants will experience what is like to work night shifts, while also being exposed to a variety of interesting tests.

An honorarium of between **R400 and R500** will be paid should you complete the full 5 shifts plus, regular snacks will be provided during each shift.

WHAT YOU HAVE TO DO: During each shift, you will be required to perform a very simple beading task.

WHAT WILL BE TESTED: A variety of physiological, subjective and performance tests; all of which will be explained to you fully.

ACCOMMODATION: As we cannot provide accommodation, you would have to either be in vacation residences or in your own digs/home.

IF YOU INTERESTED OR WOULD LIKE MORE INFORMATION, PLEASE CONTACT JONO:

Email: j.davy@ru.ac.za or Cell: 072 226 0430

7.8 LETTER TO PARTICIPANT

Dear……………………………………….

Thank you for expressing an interest to participate in this project entitled:

“**Easing the transition into night work: a comparison between alternative and established shift system designs”**

BACKGROUND AND PURPOSE OF THE CURRENT STUDY

Shift work, and particularly that which occurs at night (anytime between 20h00 and 07h00) is practised globally, as a means for industries to provide round the clock services and production. Although such an arrangement increases output and contributes significantly to any company’s “bottom line”, the costs to the human operator are significant. Very often, night shift work is associated with circadian rhythm (body clock) and sleep problems, the disruptions of which have marked impacts on a person’s ability to perform and stay safe at night. These problems stem from the fact that we are diurnal creatures and working at night essentially means that we are fighting our natural inclination to sleep during that time.

In an attempt to ease the difficulties associated with working at night, researchers have explored many different countermeasures. These include drinking coffee, exposing people to bright light, exercise, manipulating the way in which people move into and out of night work (shift system design) and strategic napping (short sleep opportunities at night).

When entering into night shift work from day or afternoon shifts, workers are forced to adjust their sleep wake cycle by as much as 8 hours, meaning that inevitably, they have to work at night and sleep during the day. This shift is similar to the effects of jet lag, in that you are forced to be awake when you should be asleep and trying to sleep when you should be awake. In an attempt to ease this transition, the current investigation will compare three different shift transition patterns to determine which one results in the least disruption to performance during the night time. The three conditions are a **standard rotating night shift** (one afternoon shift and four night shifts), an experimental **rolling shift system** (daily delay of 2 hours in the start and end times of each shift, for 5 shifts) and a **split shift nap combination** system (one afternoon shift and 4, 8 hour shift, split in to two four hour shifts that are separated by a four hour nap opportunity). All participants will also have to complete a 3 hour familiarisation session the day before the start of the actual data collection period.

PROCEDURE

During this introductory session, you will be briefed on the set up and procedures of the entire experiment. Additionally, and only after you have had all your questions answered and signed the consent form, you will have to complete a sleep disorders screening questionnaire and a morningness - eveningness questionnaire. The sleep disorder questionnaire will enable us to identify whether you have a **sleep-related problem** that could be worsened by the experiments, in which case you may be excluded from participating. The morningness - eveningness questionnaire will determine your **chronotype** (morning or evening type) and aid us in allocating you to an appropriate experimental group.

Basic demographic information such as age, sex, level of education, mass and stature will also be recorded. Following this session you will also receive a sleep diary, which I ask that you to complete for the next five days prior to starting your experimentation. Please also ensure that you complete it during the experimental period as well as the five days after you have completed the experiments.

As mentioned previously, in addition to this introduction session, you will be required to complete an **additional familiarisation session of 1 to 1.5 hours**, the day before the experiments begin. At this session, you will have the opportunity to become familiar with the task to be performed and the tests that you will be exposed to during each night shift.

In total, you will all be required to complete five 8-hour shifts, the timings of which will differ depending on the system to which you will be allocated. All data collection will occur in the Biopaharmaceutics Research Institute laboratory, which is above Rhodes House keeping and next to the African Media Matrix building.

During each shift, you will be required to perform a very simple beading task; patterns to follow will be made available and the task will be completely self-paced. During the 8 hour shift, you will also receive three, 15-minute breaks during which you will be provided with a snack to ensure that you are not hungry during the night. The frequency of these breaks may differ, depending on which shift system you are allocated to. Water and toilet facilities will always be available to you.

The performance of this beading task will be interspersed with the completion of battery of tests. In total, each of you will complete at least 6 test batteries each shift, a pre and post shift test battery and four on shift test batteries, that will occur roughly every two hours and will take no longer than 20 minutes to complete. The timings of these tests will also depend on which shift system you are allocated to.

THE TEST BATTERY

As mentioned previously, the test battery will be comprised of 5 tests.

Sensory resource tests: Reading task
You will be required to read pieces of text at varying levels of clarity, scanning them for errors as you go. This will test your ability to visually scanning and recognise objects (in this, case errors such as book).
Cognitive resource test: Memory recall task
This task will require you to perform a short number memory recall task. During this task, you will be presented (visually) with a string of numbers, which you will have to remember and recite (in the correct order) after a 10 second delay. The simple version of the test is the presentation of 5 numbers, while the complex will be the presentation of 7 numbers.

Motor resource test: Fitts' stimulus response task
The Fitts' stimulus response test measures motor program formation (the planning and execution of different movement patterns in response to a stimulus). During this test, you will be required to respond to targets appearing in random positions on a touch screen as fast and as accurately as you can, using one finger.

Accommodation task
This particular task will test your ability to accommodate (visually) to changes in your visual field. Two screens will be set up in front of you, one closer to you than the other. You will have to respond to small white squares that will appear between the different screens as quickly as possible.

Visual detection task
This task will require you to be vigilant and to recognise a critical stimulus amongst many irrelevant ones. You will be required to sit in front of a large computer screen on which there will appear many white, randomly moving stars and one red star. You will be required to respond (by clicking the mouse) when you first see the red star.

In addition to these computer and paper based tests, you will also have to rate your subjective sleepiness (how sleepy you feel) using the Karolinksa sleepiness scale; this scale has 9 verbally anchored levels of sleepiness and is very easy to understand. Furthermore, roughly every 30 minutes, I or a research assistant will record your tympanic (inner ear) temperature. This will give us some insight into how your body clock (and therefore your alertness) changes over the course of each shift. Lastly, a heart rate monitor will be fitted around your chest, and will record your heart rate during each night shift.

RISKS AND BENEFITS

The proposed study may result in the following transient effects:

- acute sleep deprivation, which is typically accompanied by feelings of lethargy, fatigue, sleepiness and increased irritability.
- In addition, for a few days after the completion of the data collection period, you may feel “unadjusted” to being awake during the day. This is a perfectly normal response to working at night and results from your body clock having tried to adjust to working at night.

However, all of the abovementioned effects are easily reversible with sleep (obtained during the normal night time), with any effects of the sleep deprivation period disappearing within two or three days after the completion of the study. Furthermore, the tests that you will be exposed to are short in duration and simple and require very little in the way of physical effort to complete.

The proposed study will also afford you the opportunity of experiencing what so many of the shift working population have to deal with on a day to day basis, while giving you an idea of the effects of sleep loss on certain (critical) cognitive processes. This will hopefully increase your own awareness of the deleterious effects of sleep loss and circadian disruptions on your own work and lifestyle.

“DO”S AND “DON’T”S

In an attempt to limit the effects of factors out of the control of the researchers, we ask that you take note and adhere to (as much as is possible) the following requirements:

- Please ensure that you maintain **a regular sleeping pattern during the 4 days prior to experimentation (at least 7 to 8 hours)**
- Record your sleeping habits in the diary provided.

24 hours before the start of and during the actual experimentation, please do not:

- Consume any alcohol
- Engage in strenuous physical activity
- Take any medication or substances that promote alertness (caffeine (in normal or filter coffee and normal tea, high energy drinks) or sleep (sleep medication, melatonin) unless prescribed to you, in which case, please inform the researchers.
- Nap during the course of the day time: try as much as possible to avoid sleep during the day and just have one monophasic period of sleep during each night prior to the study.

<u>During the data collection, we ask that you:</u>

- Not have your cell phone on you as this may interfere with the equipment while also being a distraction to you and other participants
- Not consume any of the abovementioned substances
- Report any discomfort or problems that you may be experiencing.
- Ask any questions that you may have

CONFIDENTIALITY

Please also note that all information that is collected from you before and during the course of the study period will be coded in a form that is familiar only to the principal researcher. This will ensure that all personal data cannot be linked to you at any time. The data collected will need to be saved and backed up for analyses; this will be done on the principal researcher's personal computer and flash drives, while a copy will also be stored with the principal researcher's supervisor. This information will be stored indefinitely for use in future publications, but will remain coded as well to guarantee **<u>your anonymity</u>**. Please note that your participation in the proposed study is voluntary and that you will receive some form of remuneration for participating. Furthermore, if at any stage, or for what ever reason you feel that you can no longer participate in the proposed research project, **<u>you are free to discontinue without prejudice</u>**. Additionally, if you have any questions regarding the project or need assistance in any way, please do not hesitate to contact the principal researcher (details provided below). Thank you again for your interest in the current project.

Yours sincerely,

Jonathan Davy
PHD Scholar

7.9 PARTICIPANT CONSENT FORM

I,…………………………………….. having been fully informed of the research project entitled:

“Easing the transition into night work: a comparison between alternative and established shift system designs”

Do hereby give my consent to act as a participant in the above named research. I am fully aware of the procedures involved as well as the potential risks and benefits associated with my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes. I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

PARTICIPANT (OR LEGAL REPRESENTATIVE):

……………………….	……………………..	…………………
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

………………………	……………………...	…………………..
(Print name)	(Signed)	(Date)

WITNESS:

………………………	……………………….	…………………..
(Print name)	(Signed)	(Date)

7.10 MORNINGNESS-EVENING QUESTIONNAIRE

Adapted from Horne and Ostberg, 1976

For each question, please select the answer that best describes you by circling the point that best indicates how you have felt in recent weeks.

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

   5. 5:00 AM – 6:30 AM
   4. 6:30 AM – 7:45 AM
   3. 7:45 AM – 9:45 AM
   2. 9:45 AM – 11:00 AM
   1. 11:00 AM – 12 noon

2. *Approximately* what time you go to bed if you were entirely free to plan your evening?

   5. 8:00 PM – 9:00 PM
   4. 9:00 PM – 10:15 PM
   3. 10:15 PM – 12:30 AM
   2. 12:30 AM – 1:45 AM
   1. 1:45 AM – 3:00 AM

3. If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

   4. Not all at
   3. Slightly
   2. Somewhat
   1. Very much

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

   1. Very difficult
   2. Somewhat difficult
   3. Fairly easy
   4. Very easy

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

   1. Not at all alert
   2. Slightly alert
   3. Fairly alert
   4. Very alert

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

   1. Not at all hungry
   2. Slight hungry
   3. Fairly hungry
   4. Very hungry

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

   1. Very tired
   2. Fairly tired
   3. Fairly refreshed
   4. Very refreshed

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

   1. Seldom or never later
   2. Less than 1 hour later
   3. 1-2 hours later
   4. More than 2 hours later

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

4. Would be in good form
3. Would be in reasonable form
2. Would find it difficult
1. Would find it very difficult

10. At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

5. 8:00 PM -9:00 PM
4. 9:00PM – 10:15 PM
3. 10:15 PM – 12:45 PM
2. 12:45 PM – 2:00AM
1. 2:00 AM – 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 two hours. You are entirety free to plan your day. Considering only your ‘internal clock’, which one of the four testing times would you choose?

6. 8 AM – 10 AM
4. 11 AM -1 PM
2. 3 PM – 5 PM
0. 7 PM – 9 PM

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

0. Not at all tired
1. A little tired
3. Fairly tired
5. 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?

4. Will wake up at usual time, but will not fall back asleep
3. Will wake up at usual time and will doze thereafter
2. Will wake up at usual time, but will fall asleep again
1. Will not wake up until later than usual

14. One night you have to remain awake between 4-6 AM in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

1. Would not go to bed until the watch is over
2. Would take a nap before and sleep after
3. Would take a good sleep before and nap after
4. Would sleep only before the watch

15. You have two hours of hard physical work. You are entirely free to plan your day. Considering only your internal ‘clock’, which of the following times would you choose?

4. 8 AM – 10AM
3. 11 AM - 1 PM
2. 3 PM – 5 PM
1. 7 PM – 9 PM

16. You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10 -11 PM. Bearing in mind only your internal ‘clock’, how well do you think you would perform?

1. Would be in good form
2. Would be in reasonable form
3. Would find it difficult
4. Would find it very difficult

17. Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting, and you are paid based on your performance. At *approximately* what time would you choose to begin?

5. 5 hours starting between 4-8AM
4. 5 hours starting between 8-9 AM
3. 5 hours starting between 9AM – 2 PM
2. 5 hours starting between 2 – 5 PM
1. 5 hours starting between 5 PM – 4 AM

18. At *approximately* what time of the day do you usually feel your best?

5. 5 – 8 AM
4. 8 – 10 AM
3. 10 AM – 5 PM
2. 5 – 10 PM
1. 10 PM – 5 AM

19. One hears about “morning types” and “evening types”. Which one of these types do you consider yourself to be?

6. Definitely a morning type
4. Rather more a morning type than an evening type
2. Rather more an evening type that a morning type
1. Definitely an evening type

7.11 SLEEPINESS SCALE

Karolinska sleep scale

1 Extremely alert

2 Very alert

3 Alert

4 Rather alert

5 Neither alert nor sleepy

6 Some signs of sleepiness

7 Sleepy, no effort to stay awake

8 Sleepy, some effort to stay awake

9 Very sleepy, great effort to stay awake fighting sleep

7.12 PRE TESTING SLEEP DIARY

TOTAL SLEEP TIME PER NIGHT, NUMBER OF DISTURBANCES AND OVERALL QUALITY OF SLEEP

For each day, record how much you slept in hours and minutes as well as the time (of day) that you slept and woke up. Also indicate how many times you just woke up or because you were disturbed and your overall perception of your quality of sleep. Please start to record this information from WEDNESDAY the 5TH of SEPTEMBER. The sleep time refer to those obtained at NIGHT!!!!

	PRIOR TO TESTING				
	Day 1	Day 2	Day 3	Day 4	Day 5
Time you went to bed					
Number of times you woke up					
Time you woke up					
Total sleep time (hrs & mins)	Hrs ; mins	Hrs ; mins	Hrs ; mins	Hrs ; mins	Hrs ; mins
Overall perceived quality of sleep					

***1**= very poor* *__2__ = poor* *__3__ = average* *__4__ = good* *__5__ = very good*

ADDITIONAL INFORMATION

Please indicate if you did any of the following and answer the relevant question in each statement;

	PRIOR TO TESTING				
	Day 1	Day 2	Day 3	Day 4	Day 5
Drank caffeinated drinks (How many)					
Napped (How long in hrs and mins)	Hrs ; mins	Hrs ; mins	Hrs ; mins	Hrs ; mins	
Exercise (How long)					
Drank alcohol (How many units)					
Took any medication					

7.13 EXPERIMENTAL SLEEP DIARY

TOTAL SLEEP TIME PER NIGHT, NUMBER OF DISTURBANCES AND OVERALL QUALITY OF SLEEP

For each day, record how much you slept in hours and minutes as well as the time (of day) that you slept and woke up. Also indicate how many times you just woke up or because you were disturbed and your overall perception of your quality of sleep.

	Shift 1 Afternoon shift	Shift 2 Night shift	Shift 3 Night shift	Shift 4 Night shift
Time you went to bed				
Number of times you woke up				
Time you woke up				
Total sleep time (hrs & mins)	Hrs ; mins	Hrs ; mins	Hrs ; mins	Hrs ; mins
Overall perceived quality of sleep				

***1**= very poor* *__2__ = poor* *__3__ = average* *__4__ = good* *__5__ = very good*

ADDITIONAL INFORMATION

Please indicate if you did any of the following and answer the relevant question in each statement;

	Shift 1 Afternoon shift	Shift 2 Night shift	Shift 3 Night shift	Shift 4 Night shift
Drank caffeinated drinks (How many)				
Napped (How long in hrs and mins)	Hrs ; mins	Hrs ; mins	Hrs ; mins	Hrs ; mins
Exercise (How long)				
Drank alcohol (How many units)				
Took any medication				

7.14 PARTICIPANT FOOD INTAKE OVERVIEW

Tables show all participants in each condition. An “X” indicates that participants chose to eat at when they had the opportunity.

			SHIFT 1			SHIFT 2			SHIFT 3			SHIFT 4			SHIFT 5		
	Condition	**Sex**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
A1	Fixed night	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A2	Fixed night	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A3	Fixed night	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A4	Fixed night	Female	X	X		X	X	X	X	X	X	X	X	X	X	X	X
A5	Fixed night	Female	X	X			X			X		X	X		X	X	X
A6	Fixed night	Female				X	X	X	X	X	X	X	X	X	X	X	X
A7	Fixed night	Female	X	X		X	X		X	X	X	X	X		X	X	X
A8	Fixed night	Female	X		X	X	X		X	X		X	X			X	X
A9	Fixed night	Female	X	X		X	X		X	X	X	X	X	X	X		
A10	Fixed night	Male	X	X	X		X	X	X	X	X	X	X	X	X	X	
A12	Fixed night	Male	X	X	X		X		X	X		X	X	X	X	X	

B1	Rolling	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B2	Rolling	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B4	Rolling	Female	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B5	Rolling	Female	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B6	Rolling	Female	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B7	Rolling	Female	X	X	X	X	X	X	X		X	X	X		X		X
B8	Rolling	Female	X	X	X	X	X	X	X		X	X	X	X	X	X	X
B9	Rolling	Female		X	X	X	X	X	X		X	X	X	X			X
B10	Rolling	Male	X	X	X	X	X	X	X		X	X	X	X	X	X	X
B11	Rolling	Male	X	X	X	X	X	X	X		X	X	X	X	X	X	X
B12	Rolling	Male	X	X	X	X	X	X	X		X	X	X		X	X	X

C1	Nap early	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C2	Nap early	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C3	Nap early	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C4	Nap early	Female	X	X	X	X		X	X	X	X	X		X	X	X	X
C5	Nap early	Female	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C6	Nap early	Female	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C7	Nap early	Female		X			X	X	X	X	X	X		X	X	X	
C8	Nap early	Female	X	X			X	X	X	X	X	X	X	X	X	X	X
C9	Nap early	Female	X	X	X		X	X	X	X	X	X		X	X	X	X
C11	Nap early	Male	X	X	X	X	X	X	X	X	X	X		X	X	X	X
C12	Nap early	Male		X	X	X	X	X	X	X	X	X	X	X			

D1	Nap late	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D2	Nap late	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D3	Nap late	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D4	Nap late	Female	X	X		X	X	X	X	X	X	X	X	X	X	X	X
D5	Nap late	Female	X	X		X	X	X	X	X	X	X	X	X	X	X	X
D6	Nap late	Female	X	X		X	X	X	X	X	X	X	X	X	X	X	X
D7	Nap late	Female		X	X		X	X		X	X			X		X	X
D8	Nap late	Female	X	X			X	X		X	X		X		X	X	X
D9	Nap late	Female		X			X	X		X	X				X	X	X
D10	Nap late	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D11	Nap late	Male	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D12	Nap late	Male	X	X	X		X	X	X	X	X	X	X	X	X	X	X

7.15 FOOD MENU AVAILABLE TO PARTICIPANTS

Participants had the options to order one sandwich and a drink three times during each shift. The menu included:

Bread: White or brown – participants could have two slices per feeding opportunity with a topping of their choice

Toppings:

- Full cream cheddar cheese
- Butter
- Tomatoes
- Cucumber
- Bovril (beef spread)
- Selection of cold meats: Ham, turkey, chicken or Vienna sausages
- Sauces: Mayonnaise or sweet chilli (low fat and low sugar content)

Drinks options:

- Water (ad libitum)
- Sugar free orange juice
- Rooibos tea (non-caffienated)
- Milk (low fat)
- Sweetener (Canderal)

Green apples

7.16 STATISTICAL TABLES: AFTERNOON SHIFTS

7.16.1.1.1 Beading performance

	SS	Degr. of - Freedom	MS	F	p
Intercept	16296.30	1	16296.30	294.6774	0.000000
Condition	45.36	3	15.12	0.2734	0.844230
Sex	1.01	1	1.01	0.0183	0.893082
Error	2212.09	40	55.30		
WORKPER	698.05	3	232.68	16.5845	0.000000
WORKPER*Condition	688.32	9	76.48	5.4511	0.000003
WORKPER*Sex	15.51	3	5.17	0.3686	0.775828
Error	1683.62	120	14.03		

7.16.1.1.2 Accommodation time

	SS	Degr. of - Freedom	MS	F	p
Intercept	284.4819	1	284.4819	1082.229	0.000000
Condition	0.0587	3	0.0196	0.074	0.973397
Sex	0.0463	1	0.0463	0.176	0.676897
Error	10.5147	40	0.2629		
TESTS	10.7582	5	2.1516	2.217	0.054041
TESTS*Condition	6.8903	15	0.4594	0.473	0.951831
TESTS*Sex	8.8613	5	1.7723	1.826	0.109275
Error	194.1041	200	0.9705		

7.16.1.1.3 Choice reaction time

	SS	Degr. of - Freedom	MS	F	p
Intercept	140.6679	1	140.6679	1554.234	0.000000
Condition	0.3564	3	0.1188	1.313	0.283642
Sex	0.0055	1	0.0055	0.061	0.806382
Error	3.6202	40	0.0905		
TESTS	0.2200	5	0.0440	10.290	0.000000
TESTS*Condition	0.0567	15	0.0038	0.883	0.583718
TESTS*Sex	0.0083	5	0.0017	0.388	0.856960
Error	0.8553	200	0.0043		

7.16.1.1.4 Visual detection test: reaction time (80 distractors)

	SS	Degr. of - Freedom	MS	F	p
Intercept	140.5804	1	140.5804	2141.196	0.000000
Condition	0.4138	3	0.1379	2.101	0.115358
Sex	0.0139	1	0.0139	0.212	0.647680
Error	2.6262	40	0.0657		
TESTS	0.1207	5	0.0241	1.740	0.126974
TESTS*Condition	0.4594	15	0.0306	2.209	0.007220

TESTS*Sex	0.1351	5	0.0270	1.949	0.087876
Error	2.7732	200	0.0139		

7.16.1.1.5 Visual detection test: reaction time (40 distractors)

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	132.8619	1	132.8619	1938.062	0.000000
Condition	0.4207	3	0.1402	2.046	0.122856
Sex	0.0006	1	0.0006	0.009	0.925245
Error	2.7422	40	0.0686		
TESTS	0.0457	5	0.0091	0.674	0.643973
TESTS*Condition	0.2681	15	0.0179	1.316	0.195269
TESTS*Sex	0.0448	5	0.0090	0.659	0.655038
Error	2.7168	200	0.0136		

7.16.1.1.6 Visual detection test: % overlooked (80 distractors)

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	25771.99	1	25771.99	61.76250	0.000000
Condition	1785.24	3	595.08	1.42611	0.249365
Sex	408.60	1	408.60	0.97922	0.328341
Error	16691.03	40	417.28		
TESTS	951.04	5	190.21	1.19937	0.310841
TESTS*Condition	3343.81	15	222.92	1.40564	0.147125
TESTS*Sex	252.13	5	50.43	0.31796	0.901810
Error	31718.07	200	158.59		

7.16.1.1.7 Visual detection test: % overlooked (40 distractors)

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	12166.84	1	12166.84	58.27892	0.000000
Condition	710.77	3	236.92	1.13486	0.346591
Sex	30.75	1	30.75	0.14731	0.703154
Error	8350.77	40	208.77		
TESTS	258.15	5	51.63	1.73033	0.129212
TESTS*Condition	503.20	15	33.55	1.12427	0.336514
TESTS*Sex	238.56	5	47.71	1.59898	0.161967
Error	5967.78	200	29.84		

7.16.1.1.8 Object recognition test: processing speed (low resolution)

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	10342126	1	10342126	972.5896	0.000000
Condition	46411	3	15470	1.4549	0.241337
Sex	10344	1	10344	0.9728	0.329919
Error	425344	40	10634		
TESTS	24204	5	4841	5.0026	0.000243

TESTS*Condition	15453	15	1030	1.0646	0.391648
TESTS*Sex	5860	5	1172	1.2112	0.305209
Error	193532	200	968		

7.16.1.1.9 *Object recognition: processing speed (high resolution)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	16375292	1	16375292	908.3300	0.000000
Condition	60408	3	20136	1.1169	0.353622
Sex	7665	1	7665	0.4252	0.518092
Error	721116	40	18028		
TESTS	6036	5	1207	0.9579	0.444823
TESTS*Condition	33380	15	2225	1.7657	0.041670
TESTS*Sex	7102	5	1420	1.1270	0.347245
Error	252066	200	1260		

7.16.1.1.10 *Object recognition test: errors identified (low resolution)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	641835.3	1	641835.3	987.7968	0.000000
Condition	1014.5	3	338.2	0.5205	0.673592
Sex	6062.4	1	6062.4	9.3302	0.006825
Error	11695.8	18	649.8		
TESTS	6325.0	5	1265.0	8.3808	0.000002
TESTS*Condition	7138.6	15	475.9	3.1529	0.000366
TESTS*Sex	2061.9	5	412.4	2.7321	0.024081
Error	13584.7	90	150.9		

7.16.1.1.11 *Object recognition: errors identified (high resolution)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	865494.7	1	865494.7	1471.951	0.000000
Condition	5642.6	3	1880.9	3.199	0.048278
Sex	3128.2	1	3128.2	5.320	0.033185
Error	10583.8	18	588.0		
TESTS	537.0	5	107.4	0.839	0.525198
TESTS*Condition	1891.9	15	126.1	0.986	0.476631
TESTS*Sex	1587.5	5	317.5	2.482	0.037405
Error	11513.9	90	127.9		

7.16.1.1.12 *Simple reaction time*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	23.38490	1	23.38490	2064.511	0.000000
Condition	0.05631	3	0.01877	1.657	0.191603
Sex	0.00218	1	0.00218	0.193	0.662962
Error	0.45308	40	0.01133		

TESTS	0.02926	5	0.00585	2.560	0.028554
TESTS*Condition	0.03267	15	0.00218	0.953	0.506745
TESTS*Sex	0.01347	5	0.00269	1.179	0.320786
Error	0.45712	200	0.00229		

7.16.1.1.13 *Working memory: % recalled (long delay)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	1489983	1	1489983	759.0426	0.000000
Condition	7298	3	2433	1.2393	0.308190
Sex	3960	1	3960	2.0171	0.163283
Error	78519	40	1963		
TESTS	2162	5	432	2.6553	0.023852
TESTS*Condition	2264	15	151	0.9268	0.535280
TESTS*Sex	1360	5	272	1.6707	0.143263
Error	32567	200	163		

7.16.1.1.14 *Working memory: % recalled (short delay)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	1507084	1	1507084	755.7481	0.000000
Condition	7765	3	2588	1.2979	0.288424
Sex	3708	1	3708	1.8592	0.180339
Error	79766	40	1994		
TESTS	5510	5	1102	7.4579	0.000002
TESTS*Condition	2749	15	183	1.2404	0.244163
TESTS*Sex	778	5	156	1.0533	0.387619
Error	29552	200	148		

7.16.1.1.15 *Tapping test: Motor programming time*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	5.430879	1	5.430879	398.8490	0.000000
Condition	0.055476	3	0.018492	1.3581	0.269410
Sex	0.012955	1	0.012955	0.9514	0.335227
Error	0.544655	40	0.013616		
TESTS	0.044522	5	0.008904	5.9540	0.000037
TESTS*Condition	0.029017	15	0.001934	1.2935	0.208739
TESTS*Sex	0.007311	5	0.001462	0.9777	0.432468
Error	0.299106	200	0.001496		

7.16.1.1.16 *Tapping test: High precision response time*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	212.3448	1	212.3448	2733.207	0.000000
Condition	0.4031	3	0.1344	1.730	0.176337

Sex	0.0008	1	0.0008	0.011	0.917903
Error	3.1076	40	0.0777		
TESTS	0.0135	5	0.0027	0.643	0.667031
TESTS*Condition	0.0996	15	0.0066	1.580	0.081738
TESTS*Sex	0.0535	5	0.0107	2.548	0.029222
Error	0.8403	200	0.0042		

7.16.1.1.17 *Tapping test: Low precision response time*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	179.1957	1	179.1957	3485.004	0.000000
Condition	0.2407	3	0.0802	1.560	0.213953
Sex	0.0015	1	0.0015	0.030	0.863201
Error	2.0568	40	0.0514		
TESTS	0.0115	5	0.0023	0.543	0.743788
TESTS*Condition	0.0425	15	0.0028	0.668	0.814135
TESTS*Sex	0.0572	5	0.0114	2.697	0.022059
Error	0.8478	200	0.0042		

7.16.1.1.18 *Continuous tracking test: reaction time (high sensitivity)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	17.96975	1	17.96975	43.74582	0.000000
Condition	0.94552	3	0.31517	0.76726	0.519154
Sex	2.71685	1	2.71685	6.61393	0.013940
Error	16.43106	40	0.41078		
TESTS	0.92995	5	0.18599	4.13351	0.001354
TESTS*Condition	0.48991	15	0.03266	0.72586	0.756654
TESTS*Sex	0.12984	5	0.02597	0.57714	0.717485
Error	8.99917	200	0.04500		

7.16.1.1.19 *Continuous tracking test: reaction time (low sensitivity)*

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	32.81002	1	32.81002	76.26650	0.000000
Condition	2.53638	3	0.84546	1.96526	0.134685
Sex	6.27442	1	6.27442	14.58482	0.000457
Error	17.20809	40	0.43020		
TESTS	2.53851	5	0.50770	4.04378	0.001616
TESTS*Condition	1.62689	15	0.10846	0.86387	0.605493
TESTS*Sex	1.13253	5	0.22651	1.80409	0.113588
Error	25.11025	200	0.12555		

7.16.1.1.20 *Tympanic temperature*

	SS	Degr. of - Freedom	MS	F	p
Intercept	358190.4	1	358190.4	524121.2	0.000000
Condition	1.0	3	0.3	0.5	0.676235
Sex	3.5	1	3.5	5.1	0.029278
Error	27.3	40	0.7		
TESTS	1.3	5	0.3	3.1	0.010613
TESTS*Condition	1.1	15	0.1	0.8	0.624870
TESTS*Sex	0.5	5	0.1	1.0	0.389981
Error	17.2	200	0.1		

7.16.1.1.21 *Subjective sleepiness: Karolinska sleepiness scale*

	SS	Degr. of - Freedom	MS	F	p
Intercept	3640.741	1	3640.741	475.3990	0.000000
Condition	61.800	3	20.600	2.6899	0.059110
Sex	0.749	1	0.749	0.0979	0.756037
Error	306.331	40	7.658		
TESTS	231.139	5	46.228	38.1478	0.000000
TESTS*Condition	17.758	15	1.184	0.9769	0.480903
TESTS*Sex	1.785	5	0.357	0.2946	0.915501
Error	242.361	200	1.212		

7.17 STATISTICAL TABLES: NIGHT SHIFTS

7.17.1.1.1 *Beading performance: General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	84182.99	1	84182.99	442.7360	0.000000
Condition	2079.08	3	693.03	3.6448	0.020499
Sex	107.50	1	107.50	0.5654	0.456509
Error	7605.71	40	190.14		
DAYS	408.43	3	136.14	2.7508	0.045722
DAYS*Condition	577.81	9	64.20	1.2972	0.245416
DAYS*Sex	36.76	3	12.25	0.2476	0.862899
Error	5939.05	120	49.49		
WORKPER	3082.39	3	1027.46	32.2469	0.000000
WORKPER*Condition	1501.80	9	166.87	5.2371	0.000005
WORKPER*Sex	111.04	3	37.01	1.1617	0.327350
Error	3823.49	120	31.86		
DAYS*WORKPER	324.14	9	36.02	1.1157	0.350534
DAYS*WORKPER*Condition	1654.60	27	61.28	1.8984	0.005120
DAYS*WORKPER*Sex	155.27	9	17.25	0.5344	0.849334
Error	11621.21	360	32.28		

7.17.1.1.2 *Beading performance: final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	39286.40	1	39286.40	292.1743	0.000000
Condition	1130.34	3	376.78	2.8021	0.052099
Sex	98.68	1	98.68	0.7339	0.396727
Error	5378.49	40	134.46		
DAYS	14.95	1	14.95	0.3050	0.583859
DAYS*Condition	94.15	3	31.38	0.6403	0.593593
DAYS*Sex	18.58	1	18.58	0.3791	0.541560
Error	1960.71	40	49.02		
WORKPER	1994.43	3	664.81	21.6442	0.000000
WORKPER*Condition	924.38	9	102.71	3.3439	0.001105
WORKPER*Sex	82.60	3	27.53	0.8964	0.445281
Error	3685.84	120	30.72		
DAYS*WORKPER	98.53	3	32.84	0.8570	0.465567
DAYS*WORKPER*Condition	151.82	9	16.87	0.4401	0.910765
DAYS*WORKPER*Sex	126.16	3	42.05	1.0973	0.353122
Error	4599.20	120	38.33		

7.17.1.1.3 *Accommodation time: General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	55.01433	1	55.01433	232.7097	0.000000
Condition	0.31174	3	0.10391	0.4396	0.725956
Sex	0.42698	1	0.42698	1.8061	0.186549
Error	9.45630	40	0.23641		
DAYS	0.05729	3	0.01910	1.8349	0.144469
DAYS*Condition	0.12368	9	0.01374	1.3203	0.233401
DAYS*Sex	0.01533	3	0.00511	0.4910	0.689204
Error	1.24897	120	0.01041		
TESTS	0.02939	5	0.00588	1.2183	0.301825
TESTS*Condition	0.09441	15	0.00629	1.3047	0.201822
TESTS*Sex	0.01442	5	0.00288	0.5980	0.701542
Error	0.96484	200	0.00482		
DAYS*TESTS	0.10464	15	0.00698	1.3128	0.188457
DAYS*TESTS*Condition	0.20289	45	0.00451	0.8485	0.748644
DAYS*TESTS*Sex	0.07736	15	0.00516	0.9706	0.484990
Error	3.18823	600	0.00531		

7.17.1.1.4 Accommodation time: Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	26.74783	1	26.74783	250.0923	0.000000
Condition	0.14461	3	0.04820	0.4507	0.718205
Sex	0.17656	1	0.17656	1.6509	0.206231
Error	4.27807	40	0.10695		
DAYS	0.00231	1	0.00231	0.2095	0.649667
DAYS*Condition	0.01223	3	0.00408	0.3699	0.775102
DAYS*Sex	0.00009	1	0.00009	0.0080	0.929243
Error	0.44097	40	0.01102		
TESTS	0.01904	5	0.00381	0.8153	0.539975
TESTS*Condition	0.08985	15	0.00599	1.2825	0.215712
TESTS*Sex	0.02193	5	0.00439	0.9392	0.456624
Error	0.93405	200	0.00467		
DAYS*TESTS	0.05723	5	0.01145	1.9380	0.089596
DAYS*TESTS*Condition	0.07954	15	0.00530	0.8979	0.567386
DAYS*TESTS*Sex	0.02494	5	0.00499	0.8447	0.519501
Error	1.18120	200	0.00591		

7.17.1.1.5 Choice reaction time: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	470.1779	1	470.1779	1384.806	0.000000
Condition	1.8731	3	0.6244	1.839	0.155617
Sex	0.0007	1	0.0007	0.002	0.965100
Error	13.5810	40	0.3395		
DAYS	0.1575	3	0.0525	2.574	0.057202
DAYS*Condition	0.2519	9	0.0280	1.372	0.208178
DAYS*Sex	0.0514	3	0.0171	0.840	0.474590
Error	2.4473	120	0.0204		
TESTS	0.0215	5	0.0043	1.077	0.374260
TESTS*Condition	0.0896	15	0.0060	1.496	0.109139
TESTS*Sex	0.0081	5	0.0016	0.406	0.844556
Error	0.7982	200	0.0040		
DAYS*TESTS	0.0519	15	0.0035	0.890	0.575816
DAYS*TESTS*Condition	0.2229	45	0.0050	1.274	0.113212
DAYS*TESTS*Sex	0.0431	15	0.0029	0.739	0.745835
Error	2.3323	600	0.0039		

7.17.1.1.6 Choice reaction time: Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	228.9157	1	228.9157	1312.670	0.000000
Condition	0.9508	3	0.3169	1.817	0.159513
Sex	0.0253	1	0.0253	0.145	0.705177
Error	6.9756	40	0.1744		
DAYS	0.0627	1	0.0627	1.651	0.206225
DAYS*Condition	0.1015	3	0.0338	0.891	0.453931
DAYS*Sex	0.0008	1	0.0008	0.022	0.884089
Error	1.5189	40	0.0380		
TESTS	0.0119	5	0.0024	0.668	0.648462
TESTS*Condition	0.0875	15	0.0058	1.632	0.067880
TESTS*Sex	0.0043	5	0.0009	0.239	0.944918
Error	0.7145	200	0.0036		
DAYS*TESTS	0.0241	5	0.0048	1.206	0.307793
DAYS*TESTS*Condition	0.0625	15	0.0042	1.041	0.414850
DAYS*TESTS*Sex	0.0204	5	0.0041	1.017	0.408762
Error	0.8008	200	0.0040		

7.17.1.1.7 Visual detection test: reaction time (80 distractors): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	494.4461	1	494.4461	1582.014	0.000000
Condition	0.6328	3	0.2109	0.675	0.572632
Sex	0.0448	1	0.0448	0.143	0.707052
Error	12.1891	39	0.3125		
DAYS	0.7142	3	0.2381	9.102	0.000018
DAYS*Condition	0.2209	9	0.0245	0.939	0.494679
DAYS*Sex	0.0107	3	0.0036	0.136	0.938521
Error	3.0602	117	0.0262		
TESTS	0.1217	5	0.0243	1.345	0.246973
TESTS*Condition	0.6171	15	0.0411	2.274	0.005559
TESTS*Sex	0.0539	5	0.0108	0.596	0.703031
Error	3.5273	195	0.0181		
DAYS*TESTS	0.2253	15	0.0150	0.978	0.477262
DAYS*TESTS*Condition	0.8423	45	0.0187	1.218	0.161336
DAYS*TESTS*Sex	0.3636	15	0.0242	1.578	0.074949
Error	8.9884	585	0.0154		

7.17.1.1.8 *Visual detection test: reaction time (80 distractors): Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	232.8149	1	232.8149	1358.578	0.000000
Condition	0.5848	3	0.1949	1.137	0.345906
Sex	0.0106	1	0.0106	0.062	0.804745
Error	6.6833	39	0.1714		
DAYS	0.1715	1	0.1715	9.638	0.003541
DAYS*Condition	0.0560	3	0.0187	1.049	0.381850
DAYS*Sex	0.0059	1	0.0059	0.329	0.569404
Error	0.6938	39	0.0178		
TESTS	0.0507	5	0.0101	0.658	0.655718
TESTS*Condition	0.2129	15	0.0142	0.921	0.542001
TESTS*Sex	0.1027	5	0.0205	1.333	0.251845
Error	3.0059	195	0.0154		
DAYS*TESTS	0.0623	5	0.0125	0.841	0.522074
DAYS*TESTS*Condition	0.1441	15	0.0096	0.648	0.831851
DAYS*TESTS*Sex	0.0992	5	0.0198	1.339	0.249227
Error	2.8886	195	0.0148		

7.17.1.1.9 *Visual detection test: reaction time (40 distractors): General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	468.7866	1	468.7866	1587.062	0.000000
Condition	1.4797	3	0.4932	1.670	0.189272
Sex	0.2886	1	0.2886	0.977	0.329026
Error	11.5198	39	0.2954		
DAYS	0.5173	3	0.1724	9.901	0.000007
DAYS*Condition	0.3073	9	0.0341	1.961	0.050039
DAYS*Sex	0.0907	3	0.0302	1.735	0.163586
Error	2.0375	117	0.0174		
TESTS	0.0278	5	0.0056	0.337	0.890095
TESTS*Condition	0.3659	15	0.0244	1.477	0.116865
TESTS*Sex	0.0263	5	0.0053	0.318	0.901594
Error	3.2214	195	0.0165		
DAYS*TESTS	0.2875	15	0.0192	1.241	0.236153
DAYS*TESTS*Condition	0.8347	45	0.0185	1.201	0.178913
DAYS*TESTS*Sex	0.2914	15	0.0194	1.258	0.224290
Error	9.0365	585	0.0154		

7.17.1.1.10 Visual detection: reaction time (40 distractors)

	SS	Degr. of - Freedom	MS	F	p
Intercept	224.4246	1	224.4246	1321.552	0.000000
Condition	1.1702	3	0.3901	2.297	0.092680
Sex	0.3066	1	0.3066	1.805	0.186834
Error	6.6229	39	0.1698		
DAYS	0.1503	1	0.1503	10.767	0.002183
DAYS*Condition	0.0281	3	0.0094	0.670	0.575324
DAYS*Sex	0.0001	1	0.0001	0.007	0.934454
Error	0.5444	39	0.0140		
TESTS	0.0177	5	0.0035	0.229	0.949508
TESTS*Condition	0.2153	15	0.0144	0.926	0.535780
TESTS*Sex	0.1192	5	0.0238	1.539	0.179379
Error	3.0210	195	0.0155		
DAYS*TESTS	0.0906	5	0.0181	1.119	0.351578
DAYS*TESTS*Condition	0.2667	15	0.0178	1.099	0.359804
DAYS*TESTS*Sex	0.0861	5	0.0172	1.064	0.381808
Error	3.1561	195	0.0162		

7.17.1.1.11 Visual detection test: % overlooked (80 distractors)

	SS	Degr. of - Freedom	MS	F	p
Intercept	43485.53	1	43485.53	69.27636	0.000000
Condition	4486.18	3	1495.39	2.38230	0.084134
Sex	83.21	1	83.21	0.13255	0.717765
Error	24480.73	39	627.71		
DAYS	1492.74	3	497.58	5.58563	0.001290
DAYS*Condition	637.99	9	70.89	0.79575	0.620834
DAYS*Sex	445.35	3	148.45	1.66642	0.178039
Error	10422.63	117	89.08		
TESTS	568.80	5	113.76	2.10981	0.065854
TESTS*Condition	1253.08	15	83.54	1.54931	0.091272
TESTS*Sex	74.73	5	14.95	0.27720	0.925219
Error	10514.39	195	53.92		
DAYS*TESTS	487.26	15	32.48	0.65006	0.833492
DAYS*TESTS*Condition	2226.12	45	49.47	0.98996	0.493364
DAYS*TESTS*Sex	832.98	15	55.53	1.11129	0.342207
Error	29232.96	585	49.97		

7.17.1.1.12 Visual detection test: % overlooked (80 distractors): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	16460.52	1	16460.52	48.15151	0.000000
Condition	1909.08	3	636.36	1.86153	0.152099
Sex	278.47	1	278.47	0.81460	0.372304
Error	13332.09	39	341.85		
DAYS	308.08	1	308.08	2.72924	0.106557
DAYS*Condition	218.09	3	72.70	0.64399	0.591407
DAYS*Sex	220.43	1	220.43	1.95272	0.170193
Error	4402.44	39	112.88		
TESTS	418.85	5	83.77	2.34542	0.042735
TESTS*Condition	426.28	15	28.42	0.79568	0.681622
TESTS*Sex	43.55	5	8.71	0.24387	0.942470
Error	6964.68	195	35.72		
DAYS*TESTS	137.83	5	27.57	0.84627	0.518453
DAYS*TESTS*Condition	765.12	15	51.01	1.56597	0.086153
DAYS*TESTS*Sex	255.86	5	51.17	1.57097	0.169988
Error	6351.70	195	32.57		

7.17.1.1.13 Visual detection test: % overlooked (40 distractors): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	28639.05	1	28639.05	61.12803	0.000000
Condition	1831.02	3	610.34	1.30272	0.287231
Sex	51.48	1	51.48	0.10988	0.742056
Error	18271.86	39	468.51		
DAYS	1683.65	3	561.22	13.22563	0.000000
DAYS*Condition	345.47	9	38.39	0.90458	0.523818
DAYS*Sex	124.64	3	41.55	0.97909	0.405181
Error	4964.78	117	42.43		
TESTS	1092.18	5	218.44	4.72855	0.000423
TESTS*Condition	528.79	15	35.25	0.76313	0.717149
TESTS*Sex	270.99	5	54.20	1.17324	0.323731
Error	9008.06	195	46.20		
DAYS*TESTS	661.81	15	44.12	1.18402	0.279344
DAYS*TESTS*Condition	1812.11	45	40.27	1.08066	0.337068
DAYS*TESTS*Sex	565.32	15	37.69	1.01140	0.441145
Error	21799.10	585	37.26		

7.17.1.1.14 Visual detection test: % overlooked (40 distractors): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	9756.08	1	9756.078	36.83811	0.000000
Condition	762.21	3	254.069	0.95934	0.421561
Sex	9.90	1	9.903	0.03739	0.847670
Error	10328.62	39	264.837		
DAYS	153.73	1	153.729	4.13041	0.048969
DAYS*Condition	45.18	3	15.061	0.40467	0.750458
DAYS*Sex	91.21	1	91.212	2.45070	0.125551
Error	1451.53	39	37.219		
TESTS	290.68	5	58.135	1.83505	0.107698
TESTS*Condition	285.15	15	19.010	0.60005	0.872800
TESTS*Sex	133.36	5	26.673	0.84193	0.521450
Error	6177.70	195	31.681		
DAYS*TESTS	74.77	5	14.955	0.76072	0.579170
DAYS*TESTS*Condition	500.41	15	33.360	1.69700	0.053989
DAYS*TESTS*Sex	46.52	5	9.303	0.47325	0.795927
Error	3833.40	195	19.658		

7.17.1.1.15 Object recognition test: processing speed (low resolution): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	39927823	1	39927823	756.0593	0.000000
Condition	132502	3	44167	0.8363	0.482146
Sex	230	1	230	0.0044	0.947722
Error	2059607	39	52810		
DAYS	574	3	191	0.1137	0.951920
DAYS*Condition	13879	9	1542	0.9169	0.513211
DAYS*Sex	10573	3	3524	2.0953	0.104592
Error	196790	117	1682		
TESTS	6524	5	1305	1.9126	0.093890
TESTS*Condition	7977	15	532	0.7794	0.699465
TESTS*Sex	6293	5	1259	1.8448	0.105856
Error	133040	195	682		
DAYS*TESTS	44953	15	2997	4.0905	0.000000
DAYS*TESTS*Condition	36012	45	800	1.0923	0.318952
DAYS*TESTS*Sex	9333	15	622	0.8493	0.622223
Error	428589	585	733		

7.17.1.1.16 *Object recognition: processing speed (low resolution): Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	19933832	1	19933832	689.0274	0.000000
Condition	58911	3	19637	0.6788	0.570337
Sex	3768	1	3768	0.1303	0.720121
Error	1128285	39	28930		
DAYS	31	1	31	0.0242	0.877132
DAYS*Condition	2954	3	985	0.7817	0.511374
DAYS*Sex	99	1	99	0.0787	0.780497
Error	49120	39	1259		
TESTS	15505	5	3101	3.7373	0.002971
TESTS*Condition	7282	15	485	0.5851	0.884362
TESTS*Sex	2741	5	548	0.6608	0.653629
Error	161798	195	830		
DAYS*TESTS	14692	5	2938	3.4826	0.004883
DAYS*TESTS*Condition	17786	15	1186	1.4053	0.147627
DAYS*TESTS*Sex	1861	5	372	0.4411	0.819400
Error	164533	195	844		

7.17.1.1.17 *Object recognition test: processing speed (low resolution): General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	53159747	1	53159747	770.5198	0.000000
Condition	193993	3	64664	0.9373	0.431911
Sex	91	1	91	0.0013	0.971233
Error	2690690	39	68992		
DAYS	13698	3	4566	1.9175	0.130533
DAYS*Condition	25643	9	2849	1.1966	0.303716
DAYS*Sex	22393	3	7464	3.1347	0.028202
Error	278599	117	2381		
TESTS	15462	5	3092	3.0285	0.011750
TESTS*Condition	21940	15	1463	1.4325	0.135164
TESTS*Sex	12081	5	2416	2.3663	0.041117
Error	199113	195	1021		
DAYS*TESTS	32322	15	2155	2.7770	0.000357
DAYS*TESTS*Condition	39069	45	868	1.1189	0.279762
DAYS*TESTS*Sex	10350	15	690	0.8893	0.576425
Error	453921	585	776		

7.17.1.1.18 Object recognition test: processing speed (low resolution): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	26634187	1	26634187	688.0451	0.000000
Condition	122572	3	40857	1.0555	0.379035
Sex	9736	1	9736	0.2515	0.618833
Error	1509688	39	38710		
DAYS	5535	1	5535	3.4151	0.072194
DAYS*Condition	7316	3	2439	1.5048	0.228415
DAYS*Sex	5171	1	5171	3.1910	0.081823
Error	63203	39	1621		
TESTS	18097	5	3619	3.5204	0.004537
TESTS*Condition	13738	15	916	0.8908	0.575277
TESTS*Sex	6237	5	1247	1.2134	0.304276
Error	200483	195	1028		
DAYS*TESTS	19566	5	3913	4.3367	0.000916
DAYS*TESTS*Condition	15072	15	1005	1.1135	0.346303
DAYS*TESTS*Sex	3868	5	774	0.8572	0.510926
Error	175957	195	902		

7.17.1.1.19 Object recognition: errors identified (low resolution): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	3117426	1	3117426	1419.077	0.000000
Condition	4460	3	1487	0.677	0.578126
Sex	2136	1	2136	0.972	0.337966
Error	37346	17	2197		
DAYS	5782	3	1927	8.780	0.000086
DAYS*Condition	1847	9	205	0.935	0.503717
DAYS*Sex	385	3	128	0.585	0.627399
Error	11197	51	220		
TESTS	1093	5	219	1.579	0.174598
TESTS*Condition	2480	15	165	1.194	0.292142
TESTS*Sex	894	5	179	1.292	0.275092
Error	11767	85	138		
DAYS*TESTS	6210	15	414	3.140	0.000099
DAYS*TESTS*Condition	5192	45	115	0.875	0.698429
DAYS*TESTS*Sex	2979	15	199	1.506	0.102837
Error	33621	255	132		

7.17.1.1.20 Object recognition: errors identified (low resolution): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	1689751	1	1689751	1609.171	0.000000
Condition	3100	3	1033	0.984	0.423594
Sex	456	1	456	0.434	0.518932
Error	17851	17	1050		
DAYS	494	1	494	1.599	0.223167
DAYS*Condition	850	3	283	0.917	0.453751
DAYS*Sex	39	1	39	0.127	0.726230
Error	5253	17	309		
TESTS	1420	5	284	1.838	0.114040
TESTS*Condition	1198	15	80	0.517	0.924911
TESTS*Sex	380	5	76	0.492	0.781309
Error	13137	85	155		
DAYS*TESTS	2322	5	464	3.449	0.006923
DAYS*TESTS*Condition	904	15	60	0.447	0.959215
DAYS*TESTS*Sex	746	5	149	1.108	0.362298
Error	11447	85	135		

7.17.1.1.21 Object recognition: errors identified (high resolution): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	3554034	1	3554034	1737.137	0.000000
Condition	2981	3	994	0.486	0.696704
Sex	5227	1	5227	2.555	0.128374
Error	34781	17	2046		
DAYS	4658	3	1553	12.070	0.000004
DAYS*Condition	1793	9	199	1.548	0.156663
DAYS*Sex	1610	3	537	4.171	0.010224
Error	6561	51	129		
TESTS	1933	5	387	3.080	0.013279
TESTS*Condition	3601	15	240	1.912	0.032848
TESTS*Sex	147	5	29	0.234	0.946600
Error	10673	85	126		
DAYS*TESTS	3123	15	208	2.396	0.002929
DAYS*TESTS*Condition	4910	45	109	1.256	0.141697
DAYS*TESTS*Sex	1614	15	108	1.238	0.243453
Error	22162	255	87		

7.17.1.1.22 Object recognition: errors identified (high resolution): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	1881706	1	1881706	1758.947	0.000000
Condition	2279	3	760	0.710	0.559296
Sex	717	1	717	0.670	0.424314
Error	18186	17	1070		
DAYS	228	1	228	1.952	0.180309
DAYS*Condition	579	3	193	1.655	0.214123
DAYS*Sex	279	1	279	2.394	0.140176
Error	1982	17	117		
TESTS	2365	5	473	4.481	0.001132
TESTS*Condition	3132	15	209	1.979	0.026200
TESTS*Sex	384	5	77	0.727	0.604873
Error	8971	85	106		
DAYS*TESTS	1340	5	268	2.881	0.018819
DAYS*TESTS*Condition	1616	15	108	1.159	0.319760
DAYS*TESTS*Sex	355	5	71	0.764	0.578115
Error	7903	85	93		

7.17.1.1.23 Simple reaction time: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	91.33350	1	91.33350	1839.742	0.000000
Condition	0.12976	3	0.04325	0.871	0.464218
Sex	0.00000	1	0.00000	0.000	0.997061
Error	1.93615	39	0.04964		
DAYS	0.01554	3	0.00518	1.161	0.327605
DAYS*Condition	0.02718	9	0.00302	0.677	0.728241
DAYS*Sex	0.01065	3	0.00355	0.796	0.498705
Error	0.52187	117	0.00446		
TESTS	0.07022	5	0.01404	5.870	0.000045
TESTS*Condition	0.03646	15	0.00243	1.016	0.440309
TESTS*Sex	0.01100	5	0.00220	0.919	0.469447
Error	0.46656	195	0.00239		
DAYS*TESTS	0.03285	15	0.00219	0.924	0.536968
DAYS*TESTS*Condition	0.09949	45	0.00221	0.933	0.599554
DAYS*TESTS*Sex	0.03656	15	0.00244	1.028	0.423471
Error	1.38665	585	0.00237		

7.17.1.1.24 Simple reaction time: Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	46.36296	1	46.36296	1388.606	0.000000
Condition	0.05253	3	0.01751	0.524	0.668072
Sex	0.00286	1	0.00286	0.086	0.771429
Error	1.30214	39	0.03339		
DAYS	0.00988	1	0.00988	3.115	0.085390
DAYS*Condition	0.01679	3	0.00560	1.764	0.169939
DAYS*Sex	0.00429	1	0.00429	1.352	0.252029
Error	0.12368	39	0.00317		
TESTS	0.06612	5	0.01322	5.250	0.000151
TESTS*Condition	0.03700	15	0.00247	0.979	0.478290
TESTS*Sex	0.00445	5	0.00089	0.353	0.879717
Error	0.49112	195	0.00252		
DAYS*TESTS	0.01293	5	0.00259	0.953	0.448014
DAYS*TESTS*Condition	0.04781	15	0.00319	1.174	0.294511
DAYS*TESTS*Sex	0.01014	5	0.00203	0.747	0.588981
Error	0.52925	195	0.00271		

7.17.1.1.25 Working memory: % recalled (long delay): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	7248267	1	7248267	1622.326	0.000000
Condition	48715	3	16238	3.635	0.020967
Sex	3506	1	3506	0.785	0.381147
Error	174245	39	4468		
DAYS	996	3	332	1.275	0.286256
DAYS*Condition	1232	9	137	0.526	0.853475
DAYS*Sex	1507	3	502	1.928	0.128904
Error	30480	117	261		
TESTS	1651	5	330	2.102	0.066805
TESTS*Condition	2051	15	137	0.870	0.598371
TESTS*Sex	528	5	106	0.673	0.644521
Error	30634	195	157		
DAYS*TESTS	2643	15	176	1.421	0.131666
DAYS*TESTS*Condition	6957	45	155	1.246	0.135690
DAYS*TESTS*Sex	2088	15	139	1.122	0.332257
Error	72561	585	124		

7.17.1.1.26 Working memory: % recalled (long delay): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	3647931	1	3647931	1457.970	0.000000
Condition	22677	3	7559	3.021	0.041098
Sex	468	1	468	0.187	0.667840
Error	97580	39	2502		
DAYS	14	1	14	0.077	0.782938
DAYS*Condition	280	3	93	0.529	0.664901
DAYS*Sex	51	1	51	0.288	0.594505
Error	6889	39	177		
TESTS	2158	5	432	3.311	0.006809
TESTS*Condition	1455	15	97	0.744	0.737528
TESTS*Sex	763	5	153	1.171	0.324654
Error	25416	195	130		
DAYS*TESTS	553	5	111	0.895	0.485336
DAYS*TESTS*Condition	1790	15	119	0.967	0.491850
DAYS*TESTS*Sex	601	5	120	0.973	0.435204
Error	24072	195	123		

7.17.1.1.27 Working memory: % recalled (short delay): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	7473418	1	7473418	1808.566	0.000000
Condition	48878	3	16293	3.943	0.015250
Sex	3413	1	3413	0.826	0.369185
Error	157025	38	4132		
DAYS	3538	3	1179	5.608	0.001270
DAYS*Condition	2033	9	226	1.074	0.387231
DAYS*Sex	410	3	137	0.650	0.584567
Error	23975	114	210		
TESTS	1488	5	298	1.949	0.088099
TESTS*Condition	1639	15	109	0.715	0.767253
TESTS*Sex	1509	5	302	1.976	0.083913
Error	29016	190	153		
DAYS*TESTS	2224	15	148	1.400	0.141350
DAYS*TESTS*Condition	5525	45	123	1.160	0.226138
DAYS*TESTS*Sex	3121	15	208	1.965	0.015754
Error	60350	570	106		

7.17.1.1.28 Working memory: % recalled (short delay): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	3851199	1	3851199	1743.275	0.000000
Condition	21806	3	7269	3.290	0.030835
Sex	1074	1	1074	0.486	0.489923
Error	83949	38	2209		
DAYS	514	1	514	5.624	0.022883
DAYS*Condition	431	3	144	1.574	0.211521
DAYS*Sex	241	1	241	2.634	0.112863
Error	3470	38	91		
TESTS	1213	5	243	2.642	0.024614
TESTS*Condition	1359	15	91	0.987	0.470564
TESTS*Sex	980	5	196	2.134	0.063110
Error	17444	190	92		
DAYS*TESTS	1196	5	239	2.644	0.024508
DAYS*TESTS*Condition	2049	15	137	1.510	0.104692
DAYS*TESTS*Sex	267	5	53	0.591	0.707016
Error	17183	190	90		

7.17.1.1.29 Tapping test: Motor programming time: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	60.27960	1	60.27960	421.5127	0.000000
Condition	0.53549	3	0.17850	1.2482	0.305109
Sex	0.19972	1	0.19972	1.3966	0.244274
Error	5.72031	40	0.14301		
DAYS	1.11491	3	0.37164	29.2153	0.000000
DAYS*Condition	0.09190	9	0.01021	0.8027	0.614495
DAYS*Sex	0.01435	3	0.00478	0.3760	0.770478
Error	1.52647	120	0.01272		
TESTS	0.15276	5	0.03055	8.6203	0.000000
TESTS*Condition	0.05262	15	0.00351	0.9899	0.467229
TESTS*Sex	0.00486	5	0.00097	0.2744	0.926742
Error	0.70884	200	0.00354		
DAYS*TESTS	0.05551	15	0.00370	1.1930	0.272085
DAYS*TESTS*Condition	0.11194	45	0.00249	0.8019	0.819771
DAYS*TESTS*Sex	0.02962	15	0.00197	0.6364	0.845669
Error	1.86131	600	0.00310		

7.17.1.1.30 *Tapping test: Motor programming time: Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	37.75019	1	37.75019	386.6279	0.000000
Condition	0.23949	3	0.07983	0.8176	0.491801
Sex	0.07309	1	0.07309	0.7486	0.392094
Error	3.90558	40	0.09764		
DAYS	0.00021	1	0.00021	0.0232	0.879703
DAYS*Condition	0.01046	3	0.00349	0.3820	0.766504
DAYS*Sex	0.00653	1	0.00653	0.7157	0.402578
Error	0.36521	40	0.00913		
TESTS	0.06278	5	0.01256	3.4216	0.005466
TESTS*Condition	0.04107	15	0.00274	0.7462	0.735381
TESTS*Sex	0.01178	5	0.00236	0.6419	0.667955
Error	0.73396	200	0.00367		
DAYS*TESTS	0.00662	5	0.00132	0.5940	0.704594
DAYS*TESTS*Condition	0.03190	15	0.00213	0.9540	0.505508
DAYS*TESTS*Sex	0.00622	5	0.00124	0.5577	0.732329
Error	0.44586	200	0.00223		

7.17.1.1.31 *Tapping test: High precision response time: General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	774.4452	1	774.4452	2912.461	0.000000
Condition	0.8410	3	0.2803	1.054	0.379550
Sex	0.0214	1	0.0214	0.080	0.778185
Error	10.3704	39	0.2659		
DAYS	0.0914	3	0.0305	1.475	0.224936
DAYS*Condition	0.2786	9	0.0310	1.499	0.156131
DAYS*Sex	0.0662	3	0.0221	1.069	0.365099
Error	2.4157	117	0.0206		
TESTS	0.0880	5	0.0176	3.490	0.004812
TESTS*Condition	0.1244	15	0.0083	1.645	0.065274
TESTS*Sex	0.0468	5	0.0094	1.857	0.103604
Error	0.9834	195	0.0050		
DAYS*TESTS	0.0887	15	0.0059	1.225	0.247378
DAYS*TESTS*Condition	0.1962	45	0.0044	0.903	0.654137
DAYS*TESTS*Sex	0.0435	15	0.0029	0.601	0.874933
Error	2.8243	585	0.0048		

7.17.1.1.32 Tapping test: High precision response time: Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	378.9725	1	378.9725	2818.756	0.000000
Condition	0.5755	3	0.1918	1.427	0.249553
Sex	0.0020	1	0.0020	0.015	0.904022
Error	5.2434	39	0.1344		
DAYS	0.0007	1	0.0007	0.052	0.820146
DAYS*Condition	0.0347	3	0.0116	0.854	0.473116
DAYS*Sex	0.0495	1	0.0495	3.647	0.063555
Error	0.5291	39	0.0136		
TESTS	0.0233	5	0.0047	1.113	0.354791
TESTS*Condition	0.0648	15	0.0043	1.033	0.422842
TESTS*Sex	0.0497	5	0.0099	2.377	0.040328
Error	0.8159	195	0.0042		
DAYS*TESTS	0.0253	5	0.0051	1.161	0.330073
DAYS*TESTS*Condition	0.0765	15	0.0051	1.169	0.299094
DAYS*TESTS*Sex	0.0144	5	0.0029	0.662	0.653084
Error	0.8507	195	0.0044		

7.17.1.1.33 Tapping test: Low precision response time: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	663.5956	1	663.5956	4655.903	0.000000
Condition	0.4885	3	0.1628	1.142	0.344014
Sex	0.0593	1	0.0593	0.416	0.522813
Error	5.5586	39	0.1425		
DAYS	0.0319	3	0.0106	0.572	0.634418
DAYS*Condition	0.1716	9	0.0191	1.024	0.424913
DAYS*Sex	0.0512	3	0.0171	0.917	0.434991
Error	2.1774	117	0.0186		
TESTS	0.0527	5	0.0105	2.006	0.079445
TESTS*Condition	0.1337	15	0.0089	1.696	0.054180
TESTS*Sex	0.0078	5	0.0016	0.297	0.914325
Error	1.0245	195	0.0053		
DAYS*TESTS	0.0557	15	0.0037	0.945	0.513380
DAYS*TESTS*Condition	0.1815	45	0.0040	1.027	0.427401
DAYS*TESTS*Sex	0.0800	15	0.0053	1.357	0.163224
Error	2.2986	585	0.0039		

7.17.1.1.34 *Tapping test: Low precision response time: Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	328.6465	1	328.6465	4002.096	0.000000
Condition	0.3567	3	0.1189	1.448	0.243626
Sex	0.0140	1	0.0140	0.170	0.682339
Error	3.2026	39	0.0821		
DAYS	0.0000	1	0.0000	0.001	0.969392
DAYS*Condition	0.0233	3	0.0078	0.758	0.524444
DAYS*Sex	0.0350	1	0.0350	3.419	0.072023
Error	0.3996	39	0.0102		
TESTS	0.0232	5	0.0046	1.140	0.340726
TESTS*Condition	0.0792	15	0.0053	1.298	0.206183
TESTS*Sex	0.0395	5	0.0079	1.942	0.089075
Error	0.7927	195	0.0041		
DAYS*TESTS	0.0077	5	0.0015	0.414	0.838840
DAYS*TESTS*Condition	0.0866	15	0.0058	1.555	0.089483
DAYS*TESTS*Sex	0.0318	5	0.0064	1.711	0.133671
Error	0.7242	195	0.0037		

7.17.1.1.35 *Continuous tracking test: reaction time (high sensitivity): General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	14.23319	1	14.23319	59.32864	0.000000
Condition	1.25362	3	0.41787	1.74183	0.173904
Sex	0.41668	1	0.41668	1.73687	0.195034
Error	9.59617	40	0.23990		
DAYS	0.79202	3	0.26401	12.27645	0.000000
DAYS*Condition	0.14741	9	0.01638	0.76164	0.651878
DAYS*Sex	0.04998	3	0.01666	0.77465	0.510367
Error	2.58062	120	0.02151		
TESTS	0.08471	5	0.01694	1.39234	0.228618
TESTS*Condition	0.10525	15	0.00702	0.57665	0.890699
TESTS*Sex	0.04513	5	0.00903	0.74170	0.593067
Error	2.43365	200	0.01217		
DAYS*TESTS	0.09580	15	0.00639	0.56066	0.904861
DAYS*TESTS*Condition	0.42524	45	0.00945	0.82957	0.778795
DAYS*TESTS*Sex	0.25693	15	0.01713	1.50370	0.098209
Error	6.83465	600	0.01139		

7.17.1.1.36 *Continuous tracking test: reaction time (high sensitivity): Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	4.521824	1	4.521824	59.98589	0.000000
Condition	0.390435	3	0.130145	1.72649	0.176983
Sex	0.144408	1	0.144408	1.91570	0.174006
Error	3.015259	40	0.075381		
DAYS	0.046444	1	0.046444	3.23282	0.079727
DAYS*Condition	0.047396	3	0.015799	1.09969	0.360507
DAYS*Sex	0.033655	1	0.033655	2.34261	0.133750
Error	0.574657	40	0.014366		
TESTS	0.021273	5	0.004255	0.55064	0.737717
TESTS*Condition	0.040345	15	0.002690	0.34810	0.989047
TESTS*Sex	0.010383	5	0.002077	0.26875	0.929780
Error	1.545340	200	0.007727		
DAYS*TESTS	0.015769	5	0.003154	0.57222	0.721246
DAYS*TESTS*Condition	0.105026	15	0.007002	1.27040	0.223644
DAYS*TESTS*Sex	0.015782	5	0.003156	0.57270	0.720877
Error	1.102297	200	0.005511		

7.17.1.1.37 *Continuous tracking test: reaction time (low sensitivity): General effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	22.08650	1	22.08650	73.31575	0.000000
Condition	1.08724	3	0.36241	1.20302	0.321039
Sex	0.93825	1	0.93825	3.11451	0.085232
Error	12.05007	40	0.30125		
DAYS	1.20299	3	0.40100	10.79744	0.000002
DAYS*Condition	0.47349	9	0.05261	1.41661	0.188375
DAYS*Sex	0.01953	3	0.00651	0.17527	0.912954
Error	4.45659	120	0.03714		
TESTS	0.05527	5	0.01105	0.66280	0.652095
TESTS*Condition	0.45020	15	0.03001	1.79975	0.036659
TESTS*Sex	0.20725	5	0.04145	2.48558	0.032831
Error	3.33527	200	0.01668		
DAYS*TESTS	0.49888	15	0.03326	2.11873	0.008005
DAYS*TESTS*Condition	0.92033	45	0.02045	1.30286	0.093734
DAYS*TESTS*Sex	0.60416	15	0.04028	2.56584	0.000997
Error	9.41853	600	0.01570		

7.17.1.1.38 Continuous tracking test: reaction time (low sensitivity): Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	7.413330	1	7.413330	68.60281	0.000000
Condition	0.401518	3	0.133839	1.23855	0.308437
Sex	0.387703	1	0.387703	3.58780	0.065452
Error	4.322464	40	0.108062		
DAYS	0.051725	1	0.051725	2.97945	0.092046
DAYS*Condition	0.094502	3	0.031501	1.81450	0.160032
DAYS*Sex	0.007399	1	0.007399	0.42622	0.517582
Error	0.694421	40	0.017361		
TESTS	0.053391	5	0.010678	1.16172	0.329395
TESTS*Condition	0.172647	15	0.011510	1.25220	0.235942
TESTS*Sex	0.002739	5	0.000548	0.05960	0.997643
Error	1.838336	200	0.009192		
DAYS*TESTS	0.121361	5	0.024272	3.40080	0.005692
DAYS*TESTS*Condition	0.248987	15	0.016599	2.32572	0.004432
DAYS*TESTS*Sex	0.016799	5	0.003360	0.47073	0.797800
Error	1.427444	200	0.007137		

7.17.1.1.39 Tympanic temperature: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	1372174	1	1372174	698942.3	0.000000
Condition	8	3	3	1.3	0.284957
Sex	11	1	11	5.8	0.020856
Error	77	39	2		
DAYS	1	3	0	1.0	0.381246
DAYS*Condition	4	9	0	2.3	0.022081
DAYS*Sex	0	3	0	0.4	0.748560
Error	21	117	0		
TESTS	8	5	2	22.5	0.000000
TESTS*Condition	7	15	0	6.5	0.000000
TESTS*Sex	0	5	0	0.9	0.497824
Error	13	195	0		
DAYS*TESTS	2	15	0	1.7	0.050985
DAYS*TESTS*Condition	4	45	0	1.5	0.020514
DAYS*TESTS*Sex	0	15	0	0.5	0.936974
Error	37	585	0		

7.17.1.1.40 Tympanic temperature: Final effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	685480.6	1	685480.6	623117.1	0.000000
Condition	4.2	3	1.4	1.3	0.300260
Sex	4.6	1	4.6	4.2	0.048351
Error	42.9	39	1.1		
DAYS	0.1	1	0.1	0.7	0.401631
DAYS*Condition	0.4	3	0.1	0.6	0.610369
DAYS*Sex	0.1	1	0.1	0.4	0.543850
Error	7.5	39	0.2		
TESTS	4.5	5	0.9	16.0	0.000000
TESTS*Condition	2.9	15	0.2	3.5	0.000023
TESTS*Sex	0.3	5	0.1	0.9	0.468999
Error	10.9	195	0.1		
DAYS*TESTS	0.4	5	0.1	1.3	0.273276
DAYS*TESTS*Condition	0.6	15	0.0	0.6	0.849967
DAYS*TESTS*Sex	0.1	5	0.0	0.4	0.871614
Error	12.3	195	0.1		

7.17.1.1.41 Heart rate frequency (test batteries): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	2592911	1	2592911	3377.172	0.000000
Condition	1745	3	582	0.758	0.527030
Sex	5356	1	5356	6.976	0.013166
Error	22265	29	768		
DAYS	77	2	38	0.411	0.664724
DAYS*Condition	302	6	50	0.539	0.776366
DAYS*Sex	37	2	19	0.200	0.819325
Error	5411	58	93		
TESTS	2405	4	601	32.976	0.000000
TESTS*Condition	1676	12	140	7.663	0.000000
TESTS*Sex	77	4	19	1.053	0.383201
Error	2115	116	18		
DAYS*TESTS	90	8	11	0.821	0.584831
DAYS*TESTS*Condition	176	24	7	0.535	0.964590
DAYS*TESTS*Sex	65	8	8	0.592	0.783788
Error	3170	232	14		

7.17.1.1.42 Heart rate frequency (work periods): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	2546941	1	2546941	3267.254	0.000000
Condition	1705	3	568	0.729	0.543096
Sex	4833	1	4833	6.200	0.018755
Error	22607	29	780		
DAYS	128	2	64	0.847	0.434074
DAYS*Condition	231	6	39	0.510	0.798201
DAYS*Sex	6	2	3	0.038	0.962683
Error	4381	58	76		
TESTS	1485	4	371	14.368	0.000000
TESTS*Condition	1220	12	102	3.934	0.000045
TESTS*Sex	55	4	14	0.531	0.713085
Error	2998	116	26		
DAYS*TESTS	144	8	18	1.280	0.254707
DAYS*TESTS*Condition	199	24	8	0.590	0.937588
DAYS*TESTS*Sex	55	8	7	0.486	0.865426
Error	3262	232	14		

7.17.1.1.43 r-MSSD (test batteries): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	1744049	1	1744049	743.6317	0.000000
Condition	7023	3	2341	0.9981	0.405164
Sex	1789	1	1789	0.7628	0.388395
Error	82086	35	2345		
DAYS	573	2	287	1.0900	0.341840
DAYS*Condition	1006	6	168	0.6372	0.700020
DAYS*Sex	170	2	85	0.3227	0.725264
Error	18414	70	263		
TESTS	7160	4	1790	23.9301	0.000000
TESTS*Condition	3640	12	303	4.0551	0.000021
TESTS*Sex	218	4	54	0.7282	0.574090
Error	10473	140	75		
DAYS*TESTS	480	8	60	1.2417	0.274617
DAYS*TESTS*Condition	1357	24	57	1.1711	0.267683
DAYS*TESTS*Sex	325	8	41	0.8404	0.567724
Error	13521	280	48		

7.17.1.1.44 r-MSSD (work periods): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	1807465	1	1807465	664.4574	0.000000
Condition	7082	3	2361	0.8678	0.466988
Sex	887	1	887	0.3260	0.571677
Error	95207	35	2720		
DAYS	438	2	219	0.9511	0.391240
DAYS*Condition	1055	6	176	0.7631	0.601358
DAYS*Sex	182	2	91	0.3942	0.675687
Error	16134	70	230		
TESTS	2997	4	749	8.3687	0.000004
TESTS*Condition	2069	12	172	1.9263	0.035953
TESTS*Sex	109	4	27	0.3056	0.873842
Error	12534	140	90		
DAYS*TESTS	669	8	84	2.1414	0.032211
DAYS*TESTS*Condition	956	24	40	1.0207	0.439364
DAYS*TESTS*Sex	237	8	30	0.7574	0.640667
Error	10932	280	39		

7.17.1.1.45 LFnu (test batteries): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	300.5289	1	300.5289	3412.396	0.000000
Condition	0.4984	3	0.1661	1.887	0.149317
Sex	0.0553	1	0.0553	0.628	0.433171
Error	3.1705	36	0.0881		
DAYS	0.0306	2	0.0153	0.406	0.667927
DAYS*Condition	0.1372	6	0.0229	0.607	0.724260
DAYS*Sex	0.1502	2	0.0751	1.992	0.143911
Error	2.7154	72	0.0377		
TESTS	0.0127	4	0.0032	0.892	0.470483
TESTS*Condition	0.0733	12	0.0061	1.711	0.070048
TESTS*Sex	0.0111	4	0.0028	0.775	0.543076
Error	0.5145	144	0.0036		
DAYS*TESTS	0.0348	8	0.0043	1.375	0.207122
DAYS*TESTS*Condition	0.1060	24	0.0044	1.397	0.106037
DAYS*TESTS*Sex	0.0530	8	0.0066	2.096	0.036142
Error	0.9103	288	0.0032		

7.17.1.1.46 LFnu (work periods): General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	301.9252	1	301.9252	3828.086	0.000000
Condition	0.2592	3	0.0864	1.095	0.363561
Sex	0.1228	1	0.1228	1.557	0.220205
Error	2.8394	36	0.0789		
DAYS	0.0331	2	0.0165	0.413	0.663283
DAYS*Condition	0.1009	6	0.0168	0.420	0.863571
DAYS*Sex	0.1038	2	0.0519	1.295	0.280279
Error	2.8854	72	0.0401		
TESTS	0.0256	4	0.0064	1.080	0.368775
TESTS*Condition	0.1351	12	0.0113	1.898	0.039039
TESTS*Sex	0.0147	4	0.0037	0.621	0.648468
Error	0.8543	144	0.0059		
DAYS*TESTS	0.0242	8	0.0030	0.761	0.637910
DAYS*TESTS*Condition	0.0763	24	0.0032	0.799	0.737095
DAYS*TESTS*Sex	0.0165	8	0.0021	0.518	0.842983
Error	1.1450	288	0.0040		

7.17.1.1.47 Subjective sleepiness: Karolinska sleepiness scale: General effects

	SS	Degr. of - Freedom	MS	F	p
Intercept	15501.75	1	15501.75	540.0053	0.000000
Condition	217.51	3	72.50	2.5256	0.071557
Sex	45.51	1	45.51	1.5853	0.215486
Error	1119.56	39	28.71		
DAYS	6.38	3	2.13	0.7350	0.533176
DAYS*Condition	67.06	9	7.45	2.5763	0.009629
DAYS*Sex	0.71	3	0.24	0.0824	0.969506
Error	338.39	117	2.89		
TESTS	671.25	5	134.25	54.5520	0.000000
TESTS*Condition	237.16	15	15.81	6.4245	0.000000
TESTS*Sex	14.31	5	2.86	1.1632	0.328757
Error	479.89	195	2.46		
DAYS*TESTS	38.82	15	2.59	2.5319	0.001182
DAYS*TESTS*Condition	40.98	45	0.91	0.8908	0.676034
DAYS*TESTS*Sex	8.06	15	0.54	0.5254	0.927125
Error	598.01	585	1.02		

7.17.1.1.48 *Subjective sleepiness: Karolinska sleepiness scale: Final effects*

	SS	Degr. of - Freedom	MS	F	p
Intercept	7867.651	1	7867.651	415.2151	0.000000
Condition	97.815	3	32.605	1.7207	0.178594
Sex	22.500	1	22.500	1.1874	0.282533
Error	738.987	39	18.948		
DAYS	1.591	1	1.591	0.6327	0.431165
DAYS*Condition	8.786	3	2.929	1.1648	0.335476
DAYS*Sex	0.315	1	0.315	0.1254	0.725135
Error	98.060	39	2.514		
TESTS	286.583	5	57.317	35.4329	0.000000
TESTS*Condition	96.984	15	6.466	3.9970	0.000003
TESTS*Sex	13.343	5	2.669	1.6497	0.148652
Error	315.435	195	1.618		
DAYS*TESTS	3.642	5	0.728	0.9587	0.444364
DAYS*TESTS*Condition	12.199	15	0.813	1.0703	0.386428
DAYS*TESTS*Sex	1.159	5	0.232	0.3050	0.909505

7.17.1.1.49 *Perceived sleep length during the napping opportunity*

	SS	Degr. of - Freedom	MS	F	p
Intercept	2429977	1	2429977	1975.232	0.000000
Condition	27968	1	27968	22.734	0.000117
Sex	11	1	11	0.009	0.926506
Error	24604	20	1230		
DAYS	1866	3	622	0.907	0.442960
DAYS*Condition	3384	3	1128	1.646	0.188348
DAYS*Sex	1562	3	521	0.759	0.521303
Error	41126	60	685		

7.17.1.1.50 *Perceived sleep quality during the napping opportunity*

	SS	Degr. of - Freedom	MS	F	p
Intercept	1325.718	1	1325.718	1669.569	0.000000
Condition	5.195	1	5.195	6.542	0.018761
Sex	7.172	1	7.172	9.032	0.006991
Error	15.881	20	0.794		
DAYS	1.332	3	0.444	0.732	0.536888
DAYS*Condition	0.521	3	0.174	0.286	0.835006
DAYS*Sex	7.089	3	2.363	3.898	0.013032
Error	36.373	60	0.606		

7.17.1.1.51 Reported sleep length pre data collection

	SS	Degr. of - Freedom	MS	F	p
Intercept	41820692	1	41820692	2320.684	0.000000
Condition	33827	3	11276	0.626	0.603357
Sex	10105	1	10105	0.561	0.459110
Error	612709	34	18021		
DAYS	52797	4	13199	1.375	0.245979
DAYS*Condition	95731	12	7978	0.831	0.618581
DAYS*Sex	31723	4	7931	0.826	0.510802

7.17.1.1.52 Reported sleep length for the transition from afternoon shift to night shift work

	SS	Degr. of - Freedom	MS	F	p
Intercept	13385885	1	13385885	1031.100	0.000000
Condition	283316	3	94439	7.275	0.000546
Sex	3025	1	3025	0.233	0.631992
Error	506304	39	12982		
DAYS	700444	1	700444	71.545	0.000000
DAYS*Condition	271567	3	90522	9.246	0.000095
DAYS*Sex	4080	1	4080	0.417	0.522343
Error	381822	39	9790		

7.17.1.1.53 Reported sleep length during the night shifts only (without naps)

	SS	Degr. of - Freedom	MS	F	p
Intercept	12037150	1	12037150	738.0199	0.000000
Condition	1122450	3	374150	22.9398	0.000000
Sex	2831	1	2831	0.1735	0.679261
Error	636092	39	16310		
DAYS	1646	2	823	0.1123	0.893914
DAYS*Condition	110042	6	18340	2.5021	0.028823
DAYS*Sex	4884	2	2442	0.3331	0.717680

7.17.1.1.54 Reported sleep length during the night shifts only (with naps)

	SS	Degr. of - Freedom	MS	F	p
Intercept	18847764	1	18847764	1183.345	0.000000
Condition	53469	3	17823	1.119	0.353120
Sex	26	1	26	0.002	0.968265
Error	621174	39	15928		
DAYS	7741	2	3871	0.567	0.569430
DAYS*Condition	132336	6	22056	3.232	0.006883
DAYS*Sex	4018	2	2009	0.294	0.745790