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THE IMPACT OF A ONE-HOUR SELF-SELECTED NAP OPPORTUNITY ON PHYSIOLOGICAL AND PERFORMANCE VARIABLES DURING A SIMULATED NIGHT SHIFT

BY

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ABSTRACT

Napping has been explored extensively as a means of counteracting the negative effects associated with shift work. A significant amount of this research has focused on the implementation of scheduled naps, with few studies considering flexible nap schemes. The current study therefore aimed to assess the effects of a flexible nap opportunity on the physiological, cognitive, performance, neurophysiological and subjective responses of a group of non shift workers over the course of a three-day simulated night shift regime. Additional foci were the effects of the nap condition on the extent of the circadian adaptation of the subjects to the irregular work schedule and the circadian-related influences associated with being awake during the night.

36 subjects – 18 males and 18 females – were recruited to participate in the current study. The data collection spanned twelve days, during which four, three-day long shift cycles were set up: three night shift cycles and one day shift cycle. During each night shift cycle, three separate experimental conditions were staggered, namely the nap condition, the no nap condition and a booster break condition (a collaborative study that completed the setup). The day shift served as a further comparison. Each cycle comprised of 12 subjects, which meant there were four subjects per condition during each cycle. The shifts were 8 hours in duration, with the no nap group following a standard break schedule evinced in industry. The three breaks taken during the shifts amounted to a total time of 1 hour. The nap group was afforded a 1 hour flexible nap opportunity between 00h00 and 03h00 with no other breaks. Therefore, both conditions had the same amount of work time. During the shifts, subjects performed two simple, low arousal tasks (beading and packing) and completed a test battery roughly every two hours which was comprised of physiological, performance, neurophysiological and subjective measures.

It was found that the inclusion of the nap opportunity significantly improved output performance and response time during a low precision, modified Fitts tapping task over the course of three night shifts, relative to no napping. Physiologically, napping resulted in higher heart rate frequency measures by the end of the shifts, which were also accompanied by significant reductions in subjective sleepiness ratings during all

the night shifts. The nap group's responses in this case, did not differ significantly from those of the day shift. Both simple reaction time and memory performances improved as a result of the nap inclusion, but only during the third night shift. The majority of the measures included in the research also depicted the effects of the circadian rhythm, which was indicative of the pronounced effect that this natural biological down regulation has on performance during the night. Napping reduced the severity of these effects during beading performance and measures of subjective sleepiness. With regard to habituation, the nap opportunity also resulted in positive changes in the responses of beading performance, high precision response time, simple reaction time and both subjective sleepiness measures, relative to no napping. Sleep diary responses indicated that although sleep length and quality during the day were significantly reduced for both night-time conditions, recovery sleep (length and quality) for the nap group did not differ significantly from the no nap group.

The findings of this research indicate that the inclusion of a flexible napping opportunity during the night shift had positive effects on some physiological, performance and subjective responses, and that this intervention is as beneficial as scheduled napping. Specifically, napping resulted in a significantly higher output during the beading task, relative to the no nap group despite the duration of work time being the same. As such the introduction of a flexible, self-selected nap opportunity is a practical, effective and individual-specific means of alleviating the negative effects of shift work, while improving certain performance parameters. Therefore, industries should consider its inclusion in their fatigue management programs. However, context-specific considerations must be made, with regard work scheduling, individual differences and task demands when implementing such an intervention. This will ensure that its introduction will be well received and in time, lessen the health and work-related decrements associated with shift work.

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CHAPTER I

INTRODUCTION

Shift work and specifically night shift work is globally prevalent, with its inclusion forcing workers to adopt unnatural and irregular work periods. Increased socioeconomic developments and the amplified need for the provision of services and support structures over the last two decades have resulted in a rise in the incorporation of these extended work shift days and longer work shifts (Rosa, 1993). “Shift work” refers to the extension of work into non-day hours, in which individuals have to work atypical hours, usually on a rotational basis (Åkerstedt, 1998). As a result of these irregular working hours, individuals are required to shift their normal sleeping patterns out of their natural circadian or biological rhythms to complete this work, when in actual fact, they should be sleeping. Owing to this unnatural lifestyle, shift workers have been identified as a population at risk. This is mostly due to the increased frequency of health-related decrements, specifically cardiovascular and gastrointestinal problems (Ellingsen et al., 2007), the increased manifestation of fatigue and sleepiness (Rosa, 1993; Shen et al., 2006), the development or accentuation of sleep disorders (Costa, 1997), accidents, equipment damage, personal injury and a marked reduction in performance proficiency (Åkerstedt and Landström, 1998; Rajaratnam and Arendt, 2001). Shift work has also been associated with an increased prevalence of absenteeism, job dissatisfaction, and social problems, which all place additional stress on workers, which ultimately translates into a reduction in productivity and service provision.

As a result of the very obvious negative associations shift work has, numerous countermeasures have been explored in an attempt to identify the means by which shift work-related problems can be managed (Åkerstedt and Landström, 1998; Caldwell., 2008). These have included the use of artificial light to delay circadian fluctuations at night, the use of various types of alertness-enhancing medications, such as Modafinil or more simply, caffeine, sound, temperature changes, food intake,

exercise and napping (Åkerstedt and Landström, 1998; Bonnefond et al., 2004; Caldwell, 2008). Organisational changes, such as rearrangement of shift schedules, in addition to the abovementioned factors, have also been explored (Horowitz and Tanigawa, 2002).

Napping, referring to a brief period of rest or sleep, has been extensively researched as a fatigue countermeasure and identified as a practical and easily implemented way of easing the problems associated with night work (Kogi, 1962; Naioth, 1981; Matsumoto, 1981; Matsumoto and Morita, 1987; Takahashi et al., 1999; Bonnefond et al., 2001; Takeyama et al., 2005; Kubo et al., 2007). Napping can take two forms: “prophylactic napping” refers to a phase of sleep taken prior to the period of intended sleep loss or circadian upset, as is evident during night shift work (Lavie and Weler, 1989; Bonnet and Arand, 1995; Takeyama et al., 2002). The second type of nap is more reactive in nature: the period of sleep occurs during the night shift and helps to lessen the accumulation of sleep pressure as well as the effects of the natural chronobiological sleep need (Takeyama et al., 2002). The bulk of the research in the field of napping has focused on the impacts of scheduled napping, in which the lengths and the timings have been controlled; very few studies have assessed the impact of flexible napping opportunities *in situ* and within the laboratory, and this paucity in the research needs to be adequately addressed.

STATEMENT OF PROBLEM

Shift work is practised globally and it is a well established fact that its inclusion in industry has a number of negative effects, specifically on worker health and general well being as well as operator productivity and organisational production and service delivery. These reductions in performance during the night are the product of reduced physiological arousal, cognitive slowing and lapses in attention and alertness as well as the natural and heightened presence of sleep pressure and circadian-related changes induced by being awake at irregular hours. Due to these negative and potentially threatening effects of shift work, the focus of this study was to investigate whether or not the introduction of a flexible napping scheme would have an impact on performance and subjective indicators during the course of simulated night shift work.

RESEARCH HYPOTHESIS

It is expected that the inclusion of a flexible napping scheme during the night shift will aid in improving subject performance and responses to all variables, when compared to a no napping condition. It is further expected that the self-selected chance to take a nap will show cumulative benefits over the three days of testing (habituation), with regard to the subject performance and response. Lastly, it is expected that the napping intervention will evoke a differential effect on the circadian-related changes of all measures, relative to a no nap condition.

DELIMITATIONS

Thirty six healthy student volunteers (18 and 26 years) were recruited as test subjects. All the subjects that responded met a set of criteria and completed Horne and Ostberg's (1978) Morningness-Eveningness questionnaire.

Owing to the fact that the current study took the shape of a non-repeated design, all subjects were randomly assigned to one of the three conditions: standard day, standard night (no nap) or the nap condition. They were assigned in such a way as to ensure that there was an equal distribution of males and females as well as different chronotypes. Furthermore, the 12 randomly assigned subjects in each condition were spread equally over the three night shift cycles, ensuring that there were four different nap subjects and four standard night shift subjects during all three night shift cycles (1 cycle = 3 days). A further randomisation was made with regard the testing groups within each shift cycle – the twelve subjects were randomly assigned to one of three testing groups, in which they remained for the duration of the shift cycle.

The setup and collection process was housed in a laboratory with most of the necessary facilities required to complete a project of this nature. The laboratory was quiet and removed from any significant noise distractions. With regard to the actual test battery, each group underwent testing in exactly the same order each time it occurred. Furthermore, all subjects were exposed to the same order of testing each time they came through the testing stations.

Subjects were required to complete two simple tasks for the duration of each 8 hour shift, namely a simple beading task and a packing task. With regard to the break

schedules, all breaks, including the nap, amounted to a total time of 1 hour, the arrangement of which differed between the nap and no nap conditions. Those, to whom the no nap and day conditions were applied, took the break in a room removed from the testing area, where they were provided with food and monitored by a research assistant. The napping group was afforded a 1 hour nap opportunity between the hours of 00h00 and 03h00 (this was the latest the subjects could take the nap). All subjects to whom the nap condition was applied, were exposed to a pre-nap and post-nap test. The nap environment was comfortable, dark and quiet, thus providing an adequate space in which the subjects could nap.

All subjects were provided with four small meals throughout the night: a pre-shift meal was provided on arrival at the laboratory, with all subjects in all shift cycles receiving the same type of food. All subjects were provided with the same choice of standard sandwiches at the scheduled intervals throughout the night and day shifts, ensuring that the subjects were not hungry during the course of the shift.

Throughout all the shift cycles, each subject's heart rate and heart rate variability were recorded. Additional physiological measures included skin temperature and tympanic temperature. Critical flicker fusion frequency and saccade latency, specifically prosaccade latency, were also assessed. Subject performance during the course of the shift cycles was assessed through a range of performance indicators including high and low precision performance (response time and target deviation), short term memory performance and simple reaction time. Subjective sleepiness was monitored using the Wits Sleepiness Scale and the Karolinska Sleepiness Scale. All test batteries occurred roughly every two hours during the course of the night.

LIMITATIONS

The sample group for each of the three conditions was made up of 12 subjects (three conditions = 36 subjects) and the study took the form of a non-repeated design, which may have negatively affected the statistical power of the results obtained. This could not be overcome owing to the limited laboratory size, the limited time frame during which the study could occur, as well as the limitations with regard to the amount of equipment at the researcher's disposal.

Additionally, despite the initial recruitment criteria that had to be met, there was no further screening for potential sleep disorders or medical-related problems. Owing to the fact that subjects were drawn from the student population, the researchers had no control over the activities of each subject before and after each shift. The only indication of activities outside of the laboratory was recorded in a sleep diary. Furthermore, the researchers could not gain insight into the quality and quantity of the post-shift sleep periods, or the depth of sleep during the napping opportunity, as this was not logistically possible.

Because there was a limited time frame in which the study could be completed, the shift cycles changed every three days. It would have been preferable however for the shift cycles to have been longer (±5 days), as this would have been more indicative of shift arrangements in the actual work place. Each group of subjects (each shift cycle) was not exposed to all the conditions: a repeated measures study, in which the same subjects were exposed to all the different conditions, would have made the results more comparable. However, even with a repeated measures study, transfer effects from the different conditions may have occurred which would have also made the results comparison, problematic. It would also have meant that the study would have had to have been conducted over a longer period of time, which was not possible.

The study occurred in a laboratory context and as such the tasks that the subjects had to perform may have not been indicative of tasks in the actual work place and stressors that shift workers may be exposed to.

The provision of food was crucial to avoid the effects of hunger on performance, but the thermic effect of the food may have also had an effect on the physiological responses of the subjects, which in turn may have impacted performance and subject responses. The researchers did however take note of when the food was provided so as to monitor these effects. The type of food was not strictly controlled either – subjects were provided with a choice of available sandwiches as this would be more indicative of the actual work setting where workers are required to provide or purchase their own food. However, the self regulation of food intake may have resulted in more consistent glucose levels throughout the night shifts, in that subjects chose to eat

when they felt the need to as opposed to being prescribed a time when they should eat.

The effects of the female menstrual cycle were also not taken into consideration; the hormonal fluctuations during this time have been known to affect temperature regulation, which may in turn negatively confound performance measures. It was thought that these questions would be too invasive and would also potentially limit the sample size if women who were near to or actually menstruating, were excluded from the study.

As regards heart rate and heart rate variability there are a number of factors that have been known to confound the data acquired from these measures. These include environmental temperature, the intake of food and the emotional disposition of the subjects, to name a few. The researchers could not control all of these factors.

CHAPTER II

REVIEW OF RELATED LITERATURE

SHIFT WORK

Within many industrial and service-related sectors, such as mining, chemical production, oil refinement, medical and other emergency services, there is a significant prevalence of shift work, which includes night work (Duchon et al., 1997; Härma et al., 2006). These atypical work shifts are a direct result of the simultaneous expansion of global social and economic demands (Rajaratnam and Arendt, 2001). Shift work refers to a work hour system which requires employees to continue work during the "conventional day-time third of the 24-hour cycle" (Åkerstedt, 1998: 118) and it may take different forms. These include day work, permanently displaced work hours, rotational shift work and roster work (Åkerstedt, 1998). Day workers tend to operate between 07h00 and 19h00, while permanently displaced work hours requires workers to operate during a morning shift (approximately between 06h00 to 14h00), an afternoon shift (14h00 to 22h00) or a night shift (22h00 to 06h00) (Åkerstedt, 1998). Rotational shift work requires workers to alternate between the three above mentioned shift cycles, or in some cases, just two of the shift cycles (Åkerstedt, 1998). Finally, roster work is structured in a similar way to rotational work, only the rotation is more flexible. This type of shift work system is characteristic of service-related occupations such as health care and law enforcement, as opposed to industrial operations such as mining in which fixed rotational shift work systems predominate (Åkerstedt, 1998).

In addition to the type of shift system, the speed and direction of the rotation must also be considered (Wilkinson, 1992; Knauth, 1995; Åkerstedt, 1998). As regards the speed of rotation, which refers to the number of shifts worked consecutively, shift systems may either rotate rapidly (every one, two or three days), on a weekly basis or not at all, in which case the shift system is fixed (Wilkinson, 1992). Referring to the direction of rotation, a clockwise rotation has been deemed preferable in aiding the

speed of recovery from the associated circadian disruption, despite the fact that there is no concrete evidence to support this direction of rotation: Barton and Folkard (1993) did however determine that a delaying pattern (clockwise rotation) resulted in longer sleep durations, which does assist in the recovery from such atypical schedules. van Amelsvoort et al. (2004) also determined that clockwise shift rotation resulted in better sleep quality and less work-family conflict. In addition to these organisational issues, the nature of the work being carried out, the context in which that work is performed, as well as the individual differences regarding tolerance to shift work must be considered when implementing shift systems in a particular work place (Wilkinson, 1992).

It was estimated that shift work-related accidents in the early 1990s were costing in excess of US$ 80 billion per annum (Moore-Ede, 1993). During these compressed work weeks which involve night time operations, individuals have to shift their usual sleep periods out of their natural circadian rhythms, which results in increased levels of fatigue and sleepiness, from which a plethora of negative effects on personal health and work-related accidents can develop (Duchon et al., 1997; Caldwell, 2001; Shen et al., 2006). Night shift work has been associated with reduced performance standards within work settings, an increased severity and frequency of accidents, lowered levels of production and diminished quality of products, as well as increased absenteeism and a variety of social, psychological and health-related problems (Åkerstedt, 2003; Härma et al., 2006). Rajaratnam and Arendt (2001) noted that the prevalence of accidents and error occurrence was significantly higher in the second half of the night, peaking between 02h00 and 06h00. This was in accordance with the findings of Horne and Reyner (1999), who demonstrated an increase in negative incidences during the hours of 04h00 and 06h00. The risk of fatality related to these accidents is also higher at night than during the conventional working day (Rajaratnam and Arendt, 2001).

According to Härma et al. (2006), a variety of gastrointestinal and cardiovascular diseases plague night shift workers as well, the prevalence of which is twice that found in day shift workers (Ellingsen et al., 2007). Furthermore, shift workers are at an increased risk of developing sleep disorders, which may become chronic. This is accompanied by other conditions such as lipid intolerance and possibly an increased risk of late-onset diabetes development (Costa, 1997 and Morgan et al., 1999). These

gastrointestinal problems have been linked to changes in diet that shift workers make in order to stay awake: this includes increased consumption of coffee, drugs and alcohol, the abuse of which results in the above mentioned negative effects (de Catro Moreno and Louzada, 2004). Shift work is also characterised by an increased ingestion of high caloric foods, which places an additional burden on the gastrointestinal tract. This may lead to the development of other chronic diseases of lifestyle, such as obesity (de Catro Moreno and Louzada, 2004). Socially, a lack of adequate sleep and rest outside of work may exacerbate a host of problems, such as familial issues, low morale and motivation and job dissatisfaction (Duchon et al., 1997). This sleep loss and increased levels of sleepiness may result in the accumulation of sleep debt and the development of fatigue, which in turn will also negatively impact worker performance and health (Rajaratnam and Arendt, 2001; Van Dongen, 2006).

FATIGUE AND SLEEPINESS

In most, if not all aspects of work, sport and everyday life, humans feel fatigue and sleepiness, which requires rest to recover from (Saito, 1995; Kubo et al., 2007). Fatigue and sleepiness have been described as protective processes by which organisms maintain optimal functional capabilities, as they tend to stimulate the need for rest. Therefore, the management of both phenomena is considered to be crucial, particularly for the maintenance of alertness and performance, the reduction in both erroneous behaviour and the incidences of disease, and the enhancement of general quality of life (Costa, 1996; Åkerstedt et al., 2001; Belenky et al., 2003; Van Dongen et al., 2003; Kubo et al., 2007). Shift workers are required to sleep and work at irregular times that do not coincide with their natural circadian rhythm and as a result, experience acute and chronic fatigue, sleepiness and decreased levels of vigilance (Kogi, 1962; Bonnefond et al., 2001; Kubo et al., 2007). Sleep loss and sleepiness have been linked to increased feelings of fatigue following extended wakefulness which have in turn resulted in serious human, economic and environmental damage (Dinges, 1995; Sallinen et al., 1998). Short sleep duration has also been associated with mood disturbances, immune and autonomic function impairment and hypertension (Zisapel, 2007) and it is for these reasons that these two complex phenomena need to be understood, in the attempt to counteract them.

Sleepiness

Sleepiness has become one of the main problems of society, particularly in the context of shift work (Curcio et al., 2001). Despite the fact that sleepiness is an everyday risk within the work environment, there is no universal acceptance of what being “sleepy” actually means, particularly when referring to subjective perceptions of this state (Curico et al., 2001). “Sleepiness”, from a physiological perspective, refers to the need for sleep, with this need being driven by various physiological processes, which ultimately reflect the difference between a state of being aroused and awake, and being sleepy and drowsy (Maldonado et al., 2004). From a subjective perspective, it refers to an individual’s self perception of a hypo-activated state, which manifests through self reporting, usually with the aid of a variety of sleepiness scales that are available (Curico et al, 2001). Lastly, from a behavioural standpoint, a sleepy individual often demonstrates impaired judgement and decision-making abilities, perceptual skills and reasoning abilities (Dinges and Kribbs, 1987). Together, the various standpoints may provide a holistic indicator of sleepiness, but the effects of the contextual and motivational factors on these measures, particularly those of subjective and behavioural nature, cannot be ignored (Williams et al., 1959; Dinges and Powell, 1989).

A continuous lack of adequate sleep, as experienced by shift workers also leads to the accumulation of sleep debt and if this occurs over a number of days, the sleep debt is referred to as being chronic. The concept of sleep debt has been used widely in discussions about the negative effects of shift work, untreated sleep orders that may develop from shift work, research and work-related sleep loss or restriction (Van Dongen et al., 2003). Its development results from individuals not acquiring their basal sleep need, which has been argued to be approximately 8 hours (Van Dongen et al., 2003). During shift work, workers rarely sleep for a full 8 hours owing to the fact that they have to sleep during the day. This has been found to exacerbate performance decrements during subsequent night shifts (Bonnefond et al., 2004) illustrating the effect of sleep debt on performance.

Fatigue

Despite the emphasis that has been placed on the concept of fatigue and its related negative consequences, the condition itself has no clear definition (Åkerstedt et al., 2004). It has been described as multidimensional in its origin and as such, is complex and difficult to objectively assess, as it is a very personal experience (Brown, 1982). Ream and Richardson (1996) and Shen et al., (2006) identified five distinct dimensions of fatigue: these included mental fatigue, physical fatigue, sleepiness, a lack of motivation and/or activity and general fatigue (being tired or exhausted), all of which may result from shift work or extended periods of activity when workers would normally be asleep. The standard signs of fatigue often reported are: an increased inaccuracy in controlled movements, an obvious increase in the span of anticipation or an increased response time to changes in the environment and a reduced sensitivity to changes in the body, which in the case of shift work refers to increased mood disturbances as well as uncharacteristic behavioural patterns that may result in an accident or injury (Bartlett, 1948). The harmful effects of shift work stem from what Koller (1996) refers to as a psychobiological desynchronisation and a reduced ability to cope with problems faced within the work setting. Consequently, shift workers have been identified as a population at risk. It has been and is still crucial for occupational health specialists to fully understand the context-specific reasons for the detrimental effects of night work, in order to develop and implement countermeasures specific to that particular work context and therefore limit the incidence of fatigue-related accidents, injuries and performance decrements.

Much of the research in the field of shift work has been carried out within the framework of human behaviour and physiological activation (Duffy, 1962; Rogers et al., 2003), more specifically, the inextricable link between an individual's arousal levels and his/her subsequent performance (Van Dongen and Dinges, 2003; Horowitz and Tanigawa., 2002). It has been well established that the level of physiological arousal is largely dependent on the stimulation of the individual from the task and the environment (Duffy, 1962). The fact that arousal decreases during extended (or irregular) work periods can thus be explained by the fact that there is reduced stimulation from a monotonous environment and the repetitiveness of the task (Duffy, 1962). This can be explained by the "inverted U principle", illustrated in Figure 1. This

concept describes the relationship between arousal/alertness and the resulting performance: as an individual's arousal levels decrease, performance will also be attenuated, and in the case of shift work, the effects of the monotony of the task performance are exacerbated by natural variations of circadian and homeostatic processes (Schmidt and Wrisberg, 2000). It is also important to acknowledge that the optimum level of performance arousal varies between different types of work: gross motor task performance will require much higher levels of arousal that fine motor tasks (Weinberg and Hunt, 1976).

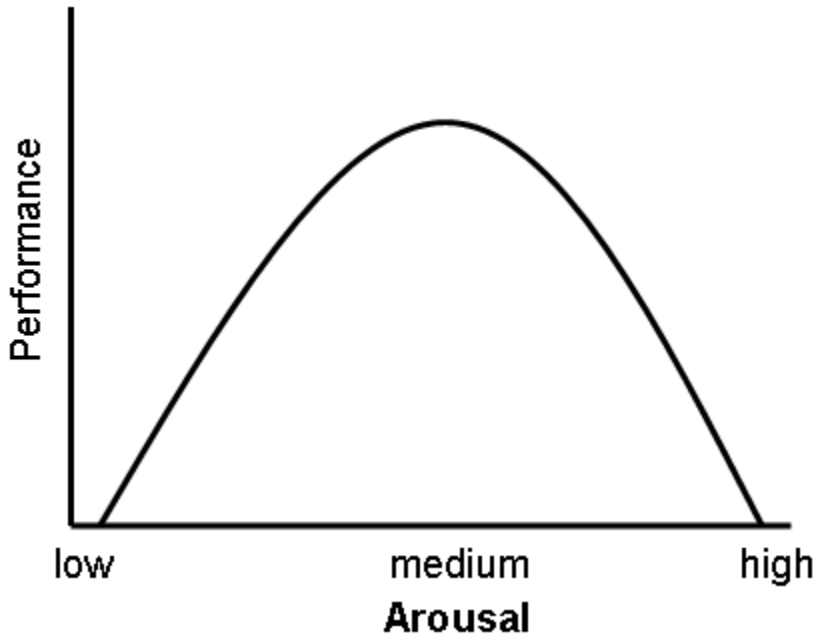

Figure 1: The Inverted "U" principle (Adapted from Schmidt and Wrisberg, 2000)

It is important to acknowledge however, that fatigue, as well as the response to shift work is an individual feeling. These differences may be endogenous to the individuals and may include factors such as circadian period length, an individual's chronotype, previous sleep duration, susceptibility to loss of sleep, age and even personality traits (Van Dogen, 2006; Acheson et al., 2007; Blatter and Cajochen, 2007). Exogenous impacting factors include work circumstances (for example, type of task, work pressures, salary concerns), social support systems, or lack thereof, home

environment (duties, opportunities to sleep, environmental stressors such as heat, cold, too much light, for example) and the presence of a secondary job or activity (Van Dogen, 2006). In addition to the above-mentioned factors and in line with the theoretical framework of human behaviour and physiological arousal, the impact of circadian changes cannot be ignored, as the associated changes may be linked to performance fluctuations throughout the night (Brown, 1982).

FACTORS AFFECTING SHIFTWORK TOLERANCE

Owing to the irregular and unnatural hours during which shift workers are made to carry out a range of jobs, extensive research has focused on identifying the fundamental factors, both human and task-orientated, that hinder effective human night time performance. This has been done in an attempt to counteract these negative manifestations.

Individual factors

Humans normally sleep at night. Currently, the physiological regulation of sleep is believed to be modulated by two separate, neurobiological systems (Borbély, 1982). Through the interaction of these two systems, humans and other mammals can achieve a consistent pattern of wakefulness and sleeping throughout a normal 24 hour day (Van Dongen, 2006; Zisapel, 2007). The oscillation of these two systems, in addition to the demands of the work task and the environmental demands, play an important function in the level of physiological arousal and hence, the performance of an individual (Brown, 1982). The first mechanism is the circadian pacemaker (*Process C)*, an internal 24-hour physiological control mechanism that is independent of sleep and waking, but one that plays a crucial role in the inception and cessation of sleep, by changing the threshold of sleep need through certain physiological fluctuations (Van Dongen, 2006; Zisapel, 2007). The second system is the homeostatic sleep process (*Process S*), which is directly influenced by the duration of prior wakefulness: the longer an individual remains awake, the higher the need or propensity for sleep will be (Carskadon and Dement, 1981; Van Dongen, 2006; Zisapel, 2007). These two systems operate simultaneously throughout the 24 hour day, albeit asynchronously.

THE CIRCADIAN RHYTHM

The activities of almost all organisms on earth tend to be influenced by a physiological cycle which is roughly 24 hours in length, termed the Circadian Rhythm (*Process C*) (Horowitz and Tanigawa., 2002). It has been identified that *Process C* is modulated by the suprachiasmatic nucleus (SCN) of the brain, more specifically, the hypothalamus (Horowitz and Tanigawa., 2002; Saper et al., 2005). Further research has divulged that individual neurons of the SCN contain a control mechanism, which is genetically predetermined, and it is these neurons that aid in the maintenance of this +/- 24 hour cycle (Horowitz and Tanigawa., 2002; Saper et al., 2005). This is achieved by a transcriptional-translational feedback loop as well as the synchronisation of this "body clock" with the external light-dark cycle (Saper et al., 2005). Fluctuations in light levels are detected by the retinal ganglion cells which feed into the SCN (Saper et al., 2005) and through a process referred to as "entrainment" (de Castro Moreno and Louzada, 2004) the synchronisation of these rhythms is governed by this external *Zeitgeber*, as well as social events such as meal times (de Castro Moreno and Louzada, 2004). This *Zeitgeber* in turn, facilitates an internal synchronisation. However, despite the considerable research into this area, the means by which this biological clock's signals are transformed into various physiological and behavioural rhythms is still not fully understood (Saper et al., 2005).

The different phases of *Process C* are evident through a number of physiological changes, such as fluctuations in the core body temperature, cortical levels and melatonin (Rajaratnam and Arendt, 2001; Horowitz and Tanigawa., 2002), while the phases of the rhythm are aligned to the sleep/wake cycle. Gilbert et al. (2004) postulated that temperature fluctuations prior to and during sleep may act as a positive feedback mechanism to keep an individual asleep. Rectal temperature, for example, will achieve a maximum at around 17h00 (referred to as the acrophase) and a minimum at roughly 05h00 (referred to as the nadir) (Åkerstdet, 2003). Melatonin on the other hand, will achieve its maximum at 04h00 and its minimum at 16h00 (Åksertedt, 2003). The arousal, alertness and performance of humans have been linked to the changes in core body temperature (CBT) (Van Dongen and Dinges, 2003; Horowitz and Tanigawa., 2002): arousal levels will be at their lowest during the nadir of *Process C*, during which time CBT is at a minimum. As mentioned, this

usually occurs between 1 and 2 hours prior to waking, but is affected by the chronotype of the individual (Duffy et al., 1999; Horowitz and Tanigawa., 2002). The reductions in temperature as a product of the time of day also result in fluctuations in heart rate (Totora and Grabowski, 2003). The question remains whether or not this relationship is causal or merely coincidental (Zisapel, 2007).

HOMEOSTATIC SLEEP PROCESS

The second and very prominent impacting factor for shift work tolerance is the homeostatic sleep process (*Process S*), which represents the drive for sleep, which increases as long as an individual is awake (Van Dongen and Dinges, 2003). The ever increasing sleep pressure, in conjunction with the physiological oscillations of the circadian rhythm, influences the need for and the onset of sleep (which allows for the recovery of resources) as well as the time of waking, once sleep pressure has been adequately dissipated (Taillard et al., 2003; Van Dongen and Dinges, 2003). This process contributes to the maintenance of internal homeostasis by preventing the complete breakdown in physiological functioning through the onset of sleep. The question about *why* humans sleep however, has yet to be fully answered, but there exists a vast base of knowledge about *how* humans sleep, with the fundamental functions of sleep now coming to light (Beersma, 1998; Fuller et al., 2006; Zisapel, 2007). Fuller et al. (2006) explained that sleep refers to a natural state that is self regulating and easily reversed, characterised by a decrease in deliberate motor activity, a reduction in responsiveness to external stimuli and a stereotypical posture of recumbency. Zisapel (2007) adds that sleep is associated with a tapering consciousness and a slowed-down metabolism. As such, sleep holds a crucial restorative function in humans and mammals. It is through studies of the effects of chronic or acute sleep deprivation that sleep has been identified as a key aspect of the “evolutionary conservation” of humans and mammals (Beersma, 1998; Durmer and Dinges, 2005). In addition to these factors, chronotype is another key factor in determining an individual’s tolerance to shift work.

CHRONOTYPE

Chronotype is a well documented dimension of personality which can be used as means of predicting an individual’s adaptability to shift work (Härma, 1993). The

concept of “Morningness-eveningness” or “chronotype” refers to an individual-specific preference in sleep timing, with morning types (MT) tending to go to sleep two hours earlier than evening types (ET) as well as to rise earlier (Mecacci and Zani, 1983; Mongrain et al., 2006). These differences have been associated with varying circadian phases, more specifically, differences in meal times, body temperature fluctuations, performance capacities, as well as melatonin and cortisol secretion over the course of a normal working day (Tankova et al., 1994; Selvi et al., 2007). Controversy exists however over the claim that ET are more adaptable to shift work than MT, but generally ET have been found to be more suitable to shift work than MT, owing to the fact that ET tend to have a better daytime recovery sleep than MT (Takeyama et al., 2002).

Takeyama et al. (2002) assessed the impact of nap provision compared to no nap for different chronotypes during a series of three simulated night shifts. The nap was scheduled between 02h00 and 04h00. Researchers monitored the effects of these conditions on mental arithmetic and typing performance, critical flicker fusion frequency and 3-choice reaction time. Additionally oral temperature, cortisol levels and heart rate variability as well as levels of fatigue and anxiety were monitored, all while considering individual differences in chronotype. It was found that the overall changes in all measures were less pronounced for ET than for MT, which led the authors to conclude that the inclusion of a night time nap was a useful way of alleviating decrements associated with shift work, especially for MT.

OTHER FACTORS

In addition to the above mentioned factors, there are a number of other individual factors that are known to affect an individual’s tolerance to shift work. As mentioned previously, these include prior sleep duration and the vulnerability of an individual to sleep loss (Aeschbach et al., 1996; Van Dongen et al., 2003). Furthermore, advances in age and limited experience with shift work have been associated with a reduced sleep quality and sleep length, which is believed to be the result of changes in these individual’s circadian physiology and a reduced speed of recovery (Åkerstedt and Torsvall, 1981). The consideration of these individual differences, as well as the demands of the workplace, is crucial when considering the planning and

implementation of fatigue management strategies (Caldwell et al., 2008). This will ensure that the measures implemented are practical and relevant to the particular workplace.

FATIGUE COUNTERMEASURES

The management of fatigue and sleepiness has been a significant challenge to a variety of production and service-related industries that practise shift work globally due to the fact there is a “no-one-size-fits-all” approach to this endeavour (Caldwell et al., 2008). Situation-specific considerations need to be made, based on the unique characteristics of the work task or service required, the shift scheduling, as well as distinct individual robustness or susceptibility to the negative impacts associated with shift work (Caldwell et al., 2008). A host of countermeasures have been applied and researched *in situ* and within a controlled laboratory setting. Such preventative measures include the use of natural or pharmacological drugs (Bonnefond et al., 2004), the use of stimulating environmental conditions including light, noise and temperature changes, as well as limiting time-on-task and finally the inclusion of behavioural and cognitive techniques (Bonnefond et al., 2004; Caldwell et al., 2008). Additional considerations with regard to the work/rest scheduling during shift work have also been made, where sleep has been acknowledged as a key component in the recovery from irregular hours of work. Periods of rest and recovery, in the form of either breaks or naps, have been known to assist in sustaining attention and limiting performance lapses associated with unnatural work hours (Caldwell et al., 2008). However, the implementation of napping is not a simple matter, the difficulties of which will subsequently be discussed.

NAPPING

“Napping” is defined as a period of sleep that is less than half the duration of a normal night’s sleep (Dinges et al., 1987). Generally, research done to date has found that napping at night has led to an increase in arousal and alertness, by supporting the natural circadian rhythm, in the short and long term, and by alleviating the effects of sleep loss (Kogi, 1962; Naioth, 1981; Matsumoto, 1981; Matsumoto and Morita, 1987; Takahashi et al., 1999; Bonnefond et al., 2001; Takeyama et al., 2005; Kubo et al., 2007). Naps have also been found to have an overall positive effect on shift workers’

health and general life quality (Kubo et al., 2007). Additional benefits of napping include reduced disruptions of physiological processes such as digestion and cardiovascular functions, which are known to be upset by irregular work hours (Bonnefond et al., 2001). A short nap at night has also been referred to as a means of “resetting” biological rhythms (Minors and Waterhouse, 1981; Bonnefond et al., 2001). In contrast to this statement, Guilleminault et al. (2006) suggest that naps may not necessarily alleviate the “chronobiological sleep pressure” created from being awake at the wrong time, but only the homeostatic sleep pressure, created from prolonged wakefulness. Global interest in napping has grown, and its broad inclusion in occupations such as those of physicians, nurses (Smith-Coggins et., al 2006; Kubo et al., 2007), aircraft pilots (Rosekind et al., 1994; Kubo et al., 2007), industrial plant operators (Bonnefond et al., 2001; Kubo et al., 2007), medical residents and interns and air craft maintenance engineers is increasing.

Despite the use of naps in industrial settings and the study of the benefits of this countermeasure in the laboratory context, it is important to consider the differing capabilities of individuals to fall asleep at night, more specifically the chronotype of the an individual (Takeyama et al., 2005), the age (Härmä, 1993; Takeyama et al., 2005) and the environment in which individuals are to take the nap (Takahashi, 2003). Naps may also interfere with subsequent day sleep, depending on the length of the night time sleep, and therefore hinder recovery between work periods (Åkerstedt et al., 1989; Sallinen et al., 1998). Matsumoto and Harada (1994) reported that following a 2-hour nap at night, subsequent day sleep was shorter, but the total sleep time did not differ between the nap and no nap conditions. However, despite all the research performed in both laboratory and field settings, the most effective type of night time nap is still a topic of great debate (Tietzel and Lack, 2001; Bonnefond et al., 2004; Kubo et al., 2007). Three crucial, interacting factors need to be taken into consideration with regard to the inclusion of naps in operational contexts: the nap length, the timing of the nap and the phase of the circadian rhythm during which the nap is to be taken (Kubo et al., 2007; Caldwell et al., 2008). As it is difficult to focus on just one of these factors exclusively, they will be discussed concurrently. The effects of sleep inertia, a negative side effect of night time napping, will also be discussed. Prior to expanding on the existing research that has focused on napping as a

countermeasure for the effects of night shift work, it is important to elaborate on the theoretical underpinnings of such a fatigue management strategy.

The resource theory proposes that an individual has a limited capacity of “resources” available for attentional processing, which may result in decrements in performance when the resource availability and its subsequent distribution do not match the demand for resources made by the task to be performed (Desmond and Matthews, 1997). In an attempt to ground the current research project, the author will extend the proposition of the resource theory, and contextualise it so as to explain the effect of shift work and the consequential circadian changes.

Night shift work has been linked to performance breakdown and increased incidences of injury and of accidents, which negatively affect the individual involved as well as the broader work environment (Åkerstedt, 2003). This performance decrement stems from the fact that these individuals are made to work against their natural, innate, biological rhythms: humans are diurnal organisms, and the primary determinant of their levels of physiological and cognitive arousal (and subsequently, their activity levels) is sunlight (de Castro Moreno and Louzada, 2004). Performance breakdown and resource consumption during the night begin with this natural upset in biological rhythm as well as the increased sleep pressure associated with staying awake during irregular hours. In addition to this cerebral and physiological slowing, task factors (physical and cognitive) accentuate the diminution of the already depleting “resources” that the body allocates for task completion. These resources become attenuated which causes the individual to attempt to access more resources to maintain the same level of performance.

This exacerbated exhaustion of these cognitive, physical and emotional “resources” finally results in a performance reduction and an additional taper in physical and cognitive functioning, which is vital to maintain the basal homeostasis within the human body. This reduction in performance provides an opportunity for the body to recoup these resources so as to function optimally in the future. This tapering is caused by numerous “protective mechanisms” that exist within the body: these mechanisms exert a “valve” effect on the diminishing resources, decreasing their distribution in situations where the central physiological, cognitive and psychosocial

homeostasis of the individual is being compromised and work output is being adversely affected. Discontinuation of all activities coincides with the appearance of a resource allocation “ceiling”: this point is characterised by the individual experiencing excessive strain, culminating in stress, which leads to the cessation of work and the onset of rest and recovery.

This concept is crucial to the understanding of why night shift work and sleep deprivation studies are relevant, but it also illustrates the difficulty associated with understanding the actual endogenous psychophysiological processes that govern performance during the night. Despite extensive research into the field of sleep and why it is essential for optimal human functioning, the fundamental reasons for why humans sleep remain elusive (Zisapel, 2007). However, through the observation of sleep-deprived humans, it is evident that any asynchronous sleeping patterns cause severe deterioration in general human operations. Within the context of shift work, performance breakdown has negative consequences for the humans involved and for the work environment in which it occurs. Consequently, various countermeasures have been explored in an attempt to prevent these negative events from occurring. One such countermeasure is the use of naps during night work (Bonnefond et al., 2001; Caldwell, 2001). The inclusion of naps during night shift work has been known to provide individuals with the opportunity to recoup resources, and prevent the potential ensuing functional breakdown and psychophysiological taper. Napping potentially alleviates increased sleep pressure, which is a direct result of the sleep homeostat and wakefulness when one should be sleeping. This in turn, aids in the maintenance of night time performance and a reduction in subjective sleepiness. An important consideration however, is the very probable manifestation of sleep inertia following the awakening from a nap taken during the night (Tassi and Muzet, 2000).

NAP LENGTH, TIMING AND CIRDIAN PHASE

Naps and their recuperative benefits have been studied extensively with naps as brief as 5 minutes proving to have a beneficial effect on night time performance (Tietzel and Lack, 2001). Extensive periods of sleep in the form of scheduled napping during night work, are not practical. Research has therefore focused on exploring the effects of varying lengths and timings of naps *in situ* and in the laboratory (Takeyama et al.,

2005). It has proven difficult to deduce an appropriate nap length and nap time to improve performance, due to the methodological differences between nap research studies. Takeyama and colleagues (2005) recommended nap lengths of between 90 and 120 minutes as being the most effective: this allows for the completion of one full sleep cycle. In terms of the placement of the nap, in relation to the circadian phase, it is important to consider the individual preferences for sleep timing, the quality of the sleep therein and the effect that the nap will have on performance just after waking and later in the shift (Caldwell et al., 2008). Significant differences in the implementation of naps in research-based projects are evident, ranging from ultra-brief naps, to more extensive periods of sleep. It is therefore important to compare the results of these various studies, the timings and lengths of the naps implemented and the impact these have on various performance-related tasks, physiological fatigue and sleepiness as well as subjective perceptions and experiences.

NAPS OF 1 HOUR OR LESS

Despite the recommendation that a nap period should be at least 2 hours in duration, a significant number of studies have assessed the effects of naps ranging from ultra-brief (10 to 30 seconds) to more prolonged periods of 1 hour. Ultra-brief naps are beyond the scope of this study and will therefore not be considered here.

Owing to the possible negative after-effects of prolonged napping, namely sleep inertia and reduced quality of daytime recovery sleep, Purnell et al. (2002) sought to determine the effects of a single 20-minute nap on aircraft maintenance engineers during 12-hour night shifts, afforded to them between 01:00 and 03:00. Through the application of subjective questionnaires and ratings of fatigue, psychomotor and vigilance performance, actigraphy and sleep diary information acquisition at the end of the shift, it was deduced that the nap yielded a positive effect on vigilance and psychomotor performance, improving accuracy and decreasing the number of performance lapses (Purnell et al., 2002). At a subjective level, alertness remained low following the nap, despite improvements in other performance tests. This was attributed to the fact that a longer nap may have been required to improve subjective alertness (Purnell et al., 2002). However subjective alertness did improve during the second night shift. In addition, the short duration of the nap did not negatively impact

subsequent day sleep. Sallinen et al. (1998) attempted to address the nap timing and length debate through the inclusion of either a 30 minute or 50 minute nap, taken at either 01:00 or 04:00, and the subsequent impact these would have on choice reaction time, sleep latency, subjective sleepiness, the level of sleep inertia and the daytime sleep following the naps. Generally, it was concluded that both nap lengths and timings had positive effects on alertness levels, as determined by the variety of tests administered. In line with the findings of Purnell and colleagues (2002), daytime sleep was only marginally affected by night time napping, however, a period of 10 to 15 minutes after the nap was ear-marked as showing evidence of sleep inertia, which may negatively impact performance (Sallinen et al., 1998).

Gillberg (1984) examined the effects of two 1 hour naps taken at 21h00 and 04h30, and determined that the later nap improved performance in choice reaction time, subjective sleepiness and sleep latency tests at the end of the night when compared to the earlier nap and no nap conditions. This was explained as being due to the later nap's proximity to the circadian trough and to the fact that this nap was longer and of a better quality than the earlier nap. This conclusion however only applies to situations where sleep loss has been marginal (less than 24 hours) (Gillberg, 1984). The placement of naps during the "circadian trough" or the nadir, which generally occurs between 03h00 and 06h00, has raised some concerns amongst specialists in the field: Dinges et al. (1985) found that subjects that awoke from a short nap during this period found it difficult and that the impairments from sleep inertia may be more pronounced than at other times in the morning, which in turn may have exacerbated performance decline. In contrast, Rogers et al. (1989) found that there were benefits (even if limited) associated with the introduction of a 1-hour nap taken at 02h00. These findings were based on a host of performance measurements, namely sustained attention, auditory vigilance, complex and visual vigilance, short term memory and two information processing and logic tasks. These authors recommended that naps of a longer duration (4-hours) would be more effective in reducing the deterioration in overnight performance, as anything shorter was deemed to be of limited benefit.

The majority of the research has been laboratory-based, but some *in situ* studies have been performed to assess the efficacy of napping: Bonnefond et al. (2001) introduced a 1 hour nap between 23h30 and 03h30 amongst shift workers in an industrial plant

for a period of one year. Through the evaluation of mood and quality of work, it was found that the general satisfaction of the workers improved, along with increased vigilance during the later parts of the night shifts. The efficacy of night time napping also improved for most workers over the year of study. Rosekind et al. (1994) and Simons and Valk (1997) studied the effects on aircraft pilots of a 40 minute in-flight nap compared to a no nap condition. These researchers determined that vigilance task performance was enhanced after the nap. However, as regards the subjective ratings of fatigue and sleepiness, the engineers stated that the nap had not alleviated fatigue levels, leading to the conclusion that subjective sleepiness responds differently to the more objective measures of fatigue (Purnell et al., 2002).

NAPS BETWEEN 1 AND 2 HOURS IN LENGTH

Matsumoto (1981) researched the effectiveness of a 2 hour nap taken at five different times during the night. Following this, it was suggested that a nap taken in the trough of the circadian rhythm was the most beneficial. However, as mentioned previously, questions arose over the effect which the ensuing sleep inertia would have on post-nap performance (Tassi and Muzet, 2000). Saito and Sasaki (1996) compared a 1 hour and 2 hour nap taken at 03h00 with a no nap condition. Subjective morning sleepiness was reduced during both nap conditions, when compared to the no nap condition. Takeyama et al. (2004) compared the effects of two differing length (60 and 120 minutes) naps taken at two different times of a night shift (00h00 or 04h00): it was established that sleep quality was superior in both the 60 minute and 120 minute naps taken at 04h00 (late naps), with the longer nap proving to be most beneficial. Task performance following both of the earlier nap conditions also improved, while the later nap conditions yielded minimal improvements, with the 60 minute nap actually resulting in performance decrements (Takeyama et al., 2004). In 2003, Matsumoto had suggested that during the earlier part of the night, longer naps would be of more benefit (120 minutes) while a 60 minute nap later in the night would aid in the maintenance of alertness following the sleep period. In essence, a longer, earlier nap would function as a prophylactic sleep, decreasing the sleep propensity which may have increased with the prolonged wakefulness over the shift, while the later, shorter nap would aid in reactively negating increased sleepiness as a product of increased

sleep pressure and circadian-related decrements in performance. A shorter nap would also hopefully limit the manifestation of excessive sleep inertia.

Despite all the research completed in the area of napping during night work, methodological differences in the application of appropriate timings and lengths of naps have made it difficult to conclusively establish a universal standard of napping for industries that incorporate shift work. These differences also demonstrate the additional complexity of this type of research in that there are a host of variables and factors that affect the results obtained. In cognisance of this problem and in the attempt to expand on existing napping literature from a different perspective, the inclusion of a flexible napping scheme was researched, particularly with reference to the associated impacts this intervention would have on early morning performance and subjective perceptions of sleepiness. One negative product of napping during the night is the development of sleep inertia that manifests itself immediately after the nap. Takeyama et al. (2005) added that the extent of sleep inertia after later naps (as a result of a superior sleep quality) is generally greater than earlier naps and it is therefore crucial that the effects of this phenomenon are not underestimated.

Sleep inertia

Sleep inertia (SI) refers to the temporary decrease in performance and disorientation that occurs directly after waking up from sleep (Tassi and Muzet, 2000). Broughton (1968) coined the term “sleep drunkenness” to describe this slowing down in performance following awakening. The extent of SI is dependent on numerous factors including the duration of sleep, the stage of sleep achieved just before waking and the period of wakefulness prior to sleep (Tassi and Muzet, 2000). No matter how long or short a sleep period is, SI will to some extent be apparent (Tassi and Muzet, 2000). A study by Jewett et al. (1999) demonstrated that after a normal 8 hour period of sleep, SI was evident in subjective alertness and cognitive output 2 hours after awakening, and even in individuals who had previously not been sleep deprived. With regard to the effects of sleep deprivation on the severity of SI, Dinges et al. (1985) found that post-nap deficits in cognitive performance were accentuated following naps that occurred after extensive bouts of sleep deprivation. In the context of shift work,

irregular sleep patterns, inadequate sleep and accumulating sleep debt may also contribute to the appearance and pronounced effect of SI.

The time of day at which an individual wakes has also been noted to have an impact on the degree of SI: Naioth et al. (1993) were among the first researchers to question whether there was an ideal time to wake to avoid the negative effects of SI, with specific regard to the influence of the circadian rhythm and the homeostatic sleep process. Following a constant work and wakefulness period of 64 hours, with 20 minute naps every 6 hours, Naioth et al. (1993) concluded that there were no precise circadian times when SI was maximal or minimal, and therefore no benefits associated with waking up at a specific time of day. In contrast to this, Dinges et al. (1985) suggested that SI was more severe when individuals woke up in the circadian nadir and less pronounced when waking occurred during the circadian peak in body temperature. The experiments carried out by Dinges et al. (1985) compared 2 hour naps placed near the circadian trough or peak following varying lengths of sleep deprivation. Despite the sleep deprivation increasing the depth of sleep during the naps, sleep periods taken near the nadir of the circadian rhythm produced significantly greater cognitive decrements than those taken near the peak, regardless of the extent of the sleep loss (Dinges et al., 1985). Another crucial consideration with regard to SI, particularly in operative and industrial contexts, is the time course and duration of the SI (Tassi and Muzet, 2000). The difficulty associated with determining this lies in the ways in which it is measured: the extent of performance decrement compared to pre-sleep performance is one method (Tassi and Muzet, 2000) while the time taken for performance to level off post-sleep, is a second method. Dinges et al. (1987) and Tassi et al. (1992) stated that the effects of SI will disappear after 30 minutes, no matter what the circumstances. Rogers et al. (1989) discovered that it took subjects more than 30 minutes to return to normal performance testing after awakening, following partial sleep deprivation. It is in fact, the effects of sleep deprivation that prolong SI: Dinges et al. (1987) and Naioth (1981) show that when sleep deprivation is significantly extended, the SI effects can last for up to 3 to 4 hours following a nap. However, Jewett et al. (1999) and Achermann et al. (1995) found that following normal sleep and waking times, there was a gradual increase in alertness and a decrease in reaction time 1 hour after waking as SI dissipated. This is important to consider when

establishing work hour management programs: it means that work places can introduce naps during work hours, as long as the workers do not suffer from prolonged sleep deprivation.

CIRCADIAN AND FATIGUE-RELATED MEASURMENT TECHNIQUES

Physiological measurements

Physiological assessment has been widely applied in the study of the effects of shift work, in that the responses indicate the effect of the circadian rhythm: the resulting variations in measures such as tympanic and skin temperature and heart rate are associated with a reduced level of arousal. This reduced arousal has in turn been linked with increased rates and incidences of injuries, errors, accidents and decreased productivity. The inclusion of measures such as heart rate variability facilitated additional insights into the effects of the unnatural work hours on autonomic regulation and function (Ito et al., 2001).

HEART RATE AND HEART RATE VARIABILITY

The measurement of heart rate (HR) is a continuous, fairly non-invasive and sensitive tool which can be used in laboratory and real work contexts as an indicator of fatigue (Apparies et al., 1998): it has been related to physical demand (Williams and Horvath, 1995; Apparies et al., 1998) and can be used to infer energy expenditure, without interfering with physical and cognitive work requirements (Apparies et al., 1998). Heart rate variability (HRV) refers to the measure of variations in the beat-to-beat (RR) interval of HR that provides insights into the effects of the sympathetic and parasympathetic systems and the broader autonomic cardiac functions (Akselrod et al., 1981; van Ravenswaaij-Arts et al., 1993).

Autonomic nervous system activity also exhibits a circadian fluctuation, whereby sympathetic nervous activity is higher during the day, and reduced at night (Furlan et al., 2000). Insights into these autonomic rhythms, particularly sympathetic (low frequency) and vagal (high frequency) variation, have been outlined as the main reason for the development of negative cardiac-related events associated with shift work (Åkerstedt et al., 1984; Furlan et al., 2000). Furthermore, Furlan et al. (2000) added that the decreased alertness and vigilance that predominates during shift work

is attended by a reduction in sympathetic tone. As such, this information may potentially be utilised as an indicator of sleepiness and reduced vigilance. HRV has also been found to reflect psychoemotional strain, which may be indicative of success or failure in accomplishing production operations as well (Andrianov and Vasilyuk, 2001). Moreover, fluctuations in HRV have also been associated with increased mental and cognitive demands, the monitoring of which is its main application and as such has also been used as an indicator of fatigue (Apparies et al., 1998).

TYMPANIC TEMPERATURE

The normal diurnal fluctuation of CBT is about 0.5^{0}C, with the lowest temperature occurring between 05h00 and 06h00, and the peak temperature occurring in the late afternoon, around 16h00 (Shephard, 1984). Over the course of the day and night, the rhythms of core temperature and sleep tendency vary inversely, however as mentioned previously, this relationship has not been fully understood (Zisapel, 2007). Human body temperature has a circadian rhythm that manifests itself through a fluctuation of between 0.8 and 1.0 ^{o} C over the day and into the night (Baker et al., 2001). This constant fluctuation is controlled (as is the broader concept of a circadian rhythm) by the suprachiasmatic nuclei, situated in the hypothalamus as well as by a host of other exogenous factors such as ambient temperature, food intake, physical activity and sleep to name but a few (Baker et al., 2001). One of many ways in which medical and scientific practitioners determine body temperature, is through the use of an Infrared Emission Detection thermometer (IRED) specifically used to determine ear or tympanic temperature (Chamberlin et al., 1995). IRED calculates body temperature by measuring the amount of infrared radiation from the tympanic membrane and auditory canal (Chamberlin et al., 1995). This method of thermometry is advantageous in that it is easy to use, it provides an immediate measure, is more hygienic than other methods, less invasive and reported to be more popular than other temperature measurement devices such as a rectal thermometer (Barber and Kilmom, 1989; Chamberlin et al., 1995).

FOREHEAD SKIN TEMPERATURE

Skin temperature fluctuates hugely, and a range of variables, including skin vasculature, ambient conditions, innate biological fluctuations, psychological and

metabolic states and physical exertion may confound skin temperature readings (Saxena and Willital, 2008). Thermography refers to the process by which body temperature is determined through the detection of electromagnetic radiation given off by body tissues or liquids (Saxena and Willitail, 2008). Despite the fact that the human body transfers heat to the environment through processes of convection, conduction, evaporation and radiation, Saxena and Willital (2008) noted that under constant conditions, which these authors state to be between 18 and 25°C, the central mechanism for temperature maintenance is radiation. The use of infrared thermal imaging has a number of advantages, namely that it is non-invasive and causes no biological side effects (Saxena and Willital, 2008), and within a work context it can be applied multiple times without interfering with work requirements, which makes its use in clinical and industrial settings very plausible.

Neurophysiological measurements

Broad research, particularly that related to driving and fatigue, has utilised a host of neurophysiological measurement tools in an attempt to identify plausible and accurate indicators fatigue, sleepiness and cognitive slowing (Lal and Craig, 2001). More specifically, these measures are applied in the attempt to assess the levels of alertness, drowsiness and sleepiness as a product of functional changes in the brain (Van Dongen and Dinges, 2000; Caffier et al., 2003). These have included electroencephalography, electro-oculograms and derivatives thereof (Lal and Craig, 2001).

Considering the abundance of motor and sensory connections between the eye and the brain, eye movement can provide insight into how drowsy an individual is (Lal and Craig, 2001). This connection also facilitates the inclusion of such measures as the threshold of critical flicker fusion frequency, which has also been a well established indicator of fatigue (Saito, 1999).

SACCADE LATENCY

A reduction in alertness levels brought about by increased levels of fatigue and sleep propensity is of major concern in industries that require the human operator to remain vigilant. The use of eye activity measures, such as electro-oculographic (EOG)

techniques, has been explored extensively. It has been established that numerous parameters of EOG measures are sensitive to the time spent performing a task, which, in the case of repetitive tasks, is indirectly linked to the inception of weariness, and hence, low alertness levels (Van Orden et al., 2000). As a result, the application of camera-based drowsiness detection devices has increased, particularly within the automobile, mining and long haul industries (Svensson, 2004; Schleicher et al., 2008). These measurements of eye movements, according to Zils et al. (2005), provide researchers with insights into the effects of fatigue on different brain functions that control eye activity.

One such EOG measure is the assessment of the latency of saccades: the term “saccades” refers to rapid eye movements used to catch an image of interest on the fovea (Crevits et al., 2003). Othani (1971) stated that saccadic movements refer to the jerky rotation of the eyes synonymous with a change in what was being looked at or the fixation point. Unlike pursuit movements, saccades are organised into distinct jumps that are accurate and unalterable once they have been initiated (Zils et al., 2005). Within different testing procedures, a number of different types of saccades may be determined: “prosaccades” refer to reflexive movements prompted by the sudden presentation of a peripheral target (Zils et al., 2005). “Antisaccades” involve the intentional termination of a saccade to a peripheral target, and the initiation of a saccade in the opposite direction. Finally, “memory-guided saccades” require an individual to remember a target position and suppress any saccadic movement to extraneous stimuli. Following a delay, the memory-guided saccade must be performed (Zils et al., 2005). In the context of this project, prosaccades and specifically their latency were assessed.

The main variables of interest with regard to saccadic performance are speed and accuracy. Speed may be assessed as latency and velocity: “latency” which refers to the simple reaction time from the presentation of the target to the initiation of the saccade. Velocity and accuracy are beyond the scope of this project and will therefore not be included in the discussion. Groner and Groner (1989) showed that saccadic latency fluctuates with changes in motivation and attention, which, it can be said, are in turn affected by sleep deprivation or sleep loss. Saccadic latency is also affected by an increased time on task with latency increasing over time (Van Orden et al., 2000).

However, of the research that has been carried out on saccades and the impact of sleep deprivation, the bulk of the results obtained have been varied and inconclusive (Zils et al., 2005).

In 2005, Zils et al. determined the effect of a full day's sleep deprivation on saccadic performance: they found that sleep deprivation had a negative impact on saccadic velocity, with accuracy of the prosaccades also being negatively affected. Latency was only prolonged for the memory-guided saccades, but not for the anitsaccades and prosaccades. This result was in agreement with the results of Crevits et al. (2003).

CRITICAL FLICKER FUSION FREQUENCY (CFFF)

CFFF is defined as the point at which a flickering light gives rise to an individual-specific and subjective perception of a steady light, which comes about through an increase or decrease in the frequency of flashing light (Smith and Misiak, 1976; Luczak and Sobolewski, 2005). When CFFF is tested, there is a distinction made between ascending and descending thresholds, with ascending thresholds indicating the lowest frequency (Hertz) at which an individual perceives there to be no more flicker (Luczak and Sobolewski, 2005). The descending threshold is indicative of the highest frequency of light at which some form of flicker appears, and due to the varying results that may be obtained from the use of either one of these two tests, the thresholds for each should be treated as separate and dissimilar phenomena (Luczak and Sobolewski, 2005).

CFFF has been and is still used in the fields of medicine and pharmacology, ophthalmology as well as psychology (Luczak and Sobolewski, 2005). It is a reliable indicator of cortex activation (Baschera and Grandjean, 1979), as the perception of the flickering light and its fusion, is affected by the level of stimulation of the retina, which in turn is directly linked and controlled by this area of the brain (Grannit and Hammond, 1931). As such, it has also been used extensively as an acceptable marker of fatigue and work over/under load (Luczak and Sobolewski, 2005). In 1978 Matsumoto et al. deduced that CFFF was directly affected by natural circadian rhythms, which became particularly evident during night shift work. At this time, particularly near the nadir of the circadian rhythm (04h00 – 06h00), significantly low CFFF levels were recorded, with the overall post shift CFFF levels being significantly

lower than the pre shift levels (Matsumoto et al., 1978). CFFF is thus thought to be impacted by work-accumulated fatigue and the resulting depressed arousal levels.

There exist however, a number of factors that have a direct impact on CFFF levels and as such, any experimental set up must take cognisance of these issues to ensure reliable results. Stimulants such as caffeine and nicotine will affect thresholds (Roback et al., 1952). Curran and Wattis (1998) outline a number of additional factors that affect the CFFF threshold. Firstly, the stimulus characteristics have a pronounced effect on the threshold level: Eisner (1995) demonstrated that as the luminance around the stimulus increases, so the CFFF threshold will decrease. It is therefore crucial that the surrounding luminance is as dark as possible. The level of environmental illumination also has a marked effect on the threshold level: significantly bright illumination will decrease the threshold and visa versa (Simonson and Brozek, 1952). The colour of the flicker is also an important variable to consider: blue light has the lowest resolution, while green light produces a higher CFFF threshold than red light (Hamer and Tyler, 1992).

With regard to subject characteristics, eye colour has been linked with variations in CFFF thresholds (Smith and Misiak, 1973). The CFFF threshold also decreases with an increase in age (Porter, 1986). Smith and Misiak (1976) also identified that CFFF thresholds are higher in individuals with larger pupils. Consequently, researchers who use CFFF must control the medications and drugs taken by their subjects as these would affect pupil size and the results obtained. An additional consideration must be given to the size of the view field in that the eyes tend to be more sensitive to flicker in the peripheral area, as opposed to the focal area.

Takeyama et al. (2004) assessed the differing effects of varied nap lengths (60 and 120 minutes) and different timings (00h00 and 04h00) on the descending threshold of CFFF: values tended to improve with both the long and short naps taken earlier in the evening, but deteriorated for the after the later 60 minute nap. This was however, not significant.

Performance measurements

According to Hockey (2000), performance refers to the mental processes that underpin mental performance. Specifically, this refers to a set of different aspects of human ability, namely perception, cognition, psychomotor processes, and the physiological and biomechanical processes that facilitate the interaction with the environment. In cognisance of this, it is assumed that task performance will provide an indirect measure of how certain mental processes cope with the task demands as well as environmental or contextual demands. Normally performance measures do not assess one of the abovementioned components, but a set of aspects that are weighted differently. As expressed in Hockey's (2000) state regulation model of compensatory control, performance can either be maintained through increased control activity and effort, with increased time on task, or effort is reduced at the cost of task performance. However, the effect of motivation cannot be ignored.

With regard to shift work, and the resultant circadian upsets, subjects have the added burden of working against their natural circadian rhythm while performing a required task, which may result in one of two developments: either performance is protected but at the cost of heightened strain (the type of which depends on the nature of the task), or performance decreases so that the strain experienced is less severe (Hockey, 2000). Therefore, very simple response variables were selected and integrated into this research, in an attempt to monitor performance over the course of the different conditions. These included simple reaction time, high and low precision performance, short term memory performance and beading performance. Beading performance was the only real indicator of work performance and it was assumed that decrements in these measures would be indicative of fatigue.

SIMPLE REACTION TIME (RT)

Reaction time (RT) refers to the interval of time between the presentation of an unanticipated stimulus and the beginning of a response to that stimulus, with simple reaction time pertaining to the presentation of just one unanticipated stimulus (Schmidt and Wrisberg, 2000). RT also represents the time taken for an individual to make a decision and implement an action, achieved through central nervous system processing - this is crucial in the working environment, particularly when driving or

operating heavy machinery. It is important however to acknowledge the fact that “movement time” (MT) is normally included in the definition of reaction time; MT refers to the period of time between the start and completion of the measured response (Oxendine, 1984). Both components form part of the overall response time, but it is generally accepted that simple responses, like the reaction test employed in this study, are considered reasonably accurate indicators of RT. Oxendine (1984) explained that it is the type of stimulus that has a marked effect on reaction time, with sound and light yielding the fastest reaction times respectively; light stimuli tend to specifically elicit a reaction time of between 0.15 and 0.25 seconds, depending on the magnitude of the response required.

“Simple reaction time” has been used extensively as a measure of the effects of sleep loss on human performance (Loh et al., 2004; Oken et al; 2006), specifically the time between stimulus input and response initiation. RT has been seen to increase during partial sleep loss or deprivation (Oken et al., 2006); Caldwell et al. (2008) noted that there is a slowing in reaction time from the resulting sleep loss associated with shift work, due to the slowing of cognitive function. Baulk et al. (2009) found similar results when comparing simple reaction time performance between day and night shifts; simple reaction time performance continued to decrease throughout the course of the night shift, with performance decrements being less pronounced during the day shift.

PRECISION TASK PERFORMANCE

Fundamentally within the realm of motor control research, one of the most common assessments of skills is the observation of the speed and accuracy taken to complete a movement (Schmidt, 1988). One particular aspect of these phenomena is the measurement of response time. Response time refers to the sum of reaction time and movement time: reaction time, as mentioned above, refers to the time taken for an individual to react to the presentation of a stimulus. Movement time refers to the defined period from the initiation of the response (the movement) to a stimulus, to the completion of the movement (Schmidt, 1988; 65).

Ngcamu (2008) explained how response time is synonymous with performance time, in that it provides insight into how the immediate working environment affects this variable and within the context of this research, how the inclusion of irregular shift

schedules will impact on performance time. Reaction time (one aspect of response time) is known to be affected by fatigue, sleep deprivation and circadian upsets (Williamson et al., 2001; Oken et al., 2006; Caldwell et al., 2008). This results from cognitive slowing which would thus increase the time between stimuli presentation and perception and initiation of a response. The measurement of response time is similar to reaction time (discussed above), the only difference being the addition of a movement component in the precision task, which provides further insights into spatial perception, motor preparation and the motor feedback loop. Further consideration must be given to the fact that tasks of this nature are affected not only by a variety of task-related factors, but also individual mental and physical capabilities (Drowatsky, 1981; Ngcamu, 2008).

In addition to the speed of response being an indicator of performance, the proficiency of performance can also be determined by the accuracy with which the movement is completed (Schmidt, 1988). The extent to which performance is affected by changes in speed and accuracy is described and explained by the speed-accuracy trade-off (Fitts, 1954; Schmidt, 1988). This concept refers to how an increase in speed during the completion of a task, upon reaching a certain essential point, will negatively impact the accuracy of the movement, which will in turn increase the occurrence of errors and decrease the precision of performance (Schmidt, 1988).

Within the context of many industries, such as the automobile industry, workers are required to perform certain tasks accurately and within a set amount of time ("tac" time), and the impact of prolonged time on task, as well as the circadian upsets associated with this type of work may affect precision performance, resulting in increased errors (Hockey, 1997). Williamson et al. (2001) found that the circadian rhythm had a pronounced effect on the speed of movement, but not accuracy, which suggests that shift work and the associated cognitive slowing, may negatively affect early morning performance of this kind. Moreover, these authors claimed that, with regard to the effects of sleep loss, subjects chose to slow down during precision performance, so as to maximise accuracy.

Cognitive performance measurements

SHORT TERM (WORKING) MEMORY

Fluctuations in cognitive functioning, as a product of circadian rhythm changes, have been of interest, with a general consensus that performance is best when body temperature is at its highest and worst when body temperature is at its lowest, but only during procedural or routine tasks. These included reaction time, card sorting, multiplication speed and code transcription (Kleitman, 1963). Kleitman's hypothesis has been supported through studies of neurobehavioural performances during shift work and continuous night operations, where a positive relationship between daily fluctuations in body temperature and human performance has been established (Wright et al., 2002). Short term memory performance is one aspect of higher cognitive functioning that is affected by circadian upsets. STM or working memory refers to the ability to temporarily store limited amounts of information while performing a particular physical or mental operation (Bridger, 2003). The commitment of information to this form of memory requires considerable mental resources, specifically attention and as such, any distractions or loss of concentration will result in that information, being lost (Bridger, 2003). It is well established that STM has a limited storage capacity, with a figure of 7 "chunks" ±2 generally being applied while the retention interval ranges between 5 and 30 seconds (Bridger, 2003). Changes in working memory performance have been linked to changes in body temperature and alertness levels; Wright et al. (2002) assessed the impact of circadian-related changes in body temperature on memory performance. These authors found that working memory fluctuated with changes in the circadian rhythm, and declined as a function of time awake (Wright et al., 2002).

Furthermore, sustained periods of work, particularly during irregular night shift work, and any sleep-related problems linked with shift work have been known to distort cognitive and perceptual functions (Krueger, 1989). Sleep loss decreases attention and vigilance, which in turn, will have a negative impact on working memory. Rogers et al. (1989) discovered that the inclusion of a 1hour nap at 02h00 over one night of wakefulness had a limited benefit on short term memory, which did not significantly change over the course of the night.

Smith-Coggins et al. (2006) assessed the impact that a 40 minute nap opportunity had on nurses during the course of a 12-hour night shift. Through the application of the Probed Memory Recall task, it was found that memory performance just after the nap decreased significantly, compared to subjects that did not nap. However during later tests, performance improved and returned to levels similar to those of the no-nap group.

Subjective measurements

SUBJECTIVE SLEEPINESS

“Subjective sleepiness” refers to an individual’s self perception of their hypo-activated state, the scales for which consider sleepiness as a state characteristic, evoked through either daily fluctuations in physiological (circadian) arousal or by irregular sleeping and waking patterns, as evident in shift work (Curcio et al., 2001). It is the imbalance between the sleep and wake mechanisms created by shift work, that result in feelings and physiological manifestations of sleepiness (Shen et al., 2006). Through the application of scales such as the Karolinska Sleepiness scale and the Wits Sleepiness scale, both of which measure subjective sleepiness at a particular time, insights into the impact that circadian factors and shift work would have on subjective feelings, are made possible (Shen et al., 2006).

KAROLINKSA SLEEPINESS SCALE (KSS)

Subjective reports of sleepiness are a convenient and rapid means of determining the extent of sleepiness both in laboratory and *in situ* contexts. The KSS has been validated against alpha and theta electroencephalogram (EEG) activity as well as electro-oculograpahic measures of slow eye movement (Åkerstedt and Gillberg, 1990; Kaida et al., 2006), but concerns over the actual meaning of the different levels of the scale do exist, with regards their relation to other electrophysiological measures. Guilleminault and Brooks (2001) question the scale’s applicability to the assessment of global feelings of sleepiness: they comment that, like the Standford Sleepiness Scale, the KSS is a good indicator of momentary sleepiness within a given time frame.

Due to the ease with which the scale can be applied, it has been extensively utilised as a subjective indicator of sleepiness in numerous studies: Sallinen et al. (2005)

assessed the impact on sleepiness of various combinations of shift scheduling. Within this study, ratings of higher than 7 on the KSS “sleepy but not fighting sleep” were considered as severe, the overall prevalence of which was 50.5% with shift combinations that ended with a night shift, compared to 18.6% associated with morning shifts (Sallinen et al., 2005). Similarly, Gillberg et al. (1994) found that sleepiness measures, as assessed by the KSS, increased with increased time of wakefulness. These authors also found that higher levels of sleepiness ratings and decreased task performance, namely vigilance and simple reaction time, showed a high correlation. Specific to the effects of napping on subjective sleepiness, Sallinen et al. (1998) compared the effects of either a 30 or a 50-minute nap, taken early (01h00) or late (04h00). For both conditions, subjective sleepiness tended to increase across the night awake. However, the ratings for the nap conditions increased at a slower rate when compared to the no nap control group (Sallinen et al., 1998). The effect of a 40-minute nap opportunity in 3 consecutive 12-hour night shifts on the cognitive, subjective and psychomotor performance of physicians and nurses yielded significantly reduced levels of subjective sleepiness amongst the napping group on the morning after the third night shift, compared to the level of the no nap group (Smith-Coggins et al., 2006).

Åkerstedt et al. (2005) compared simulator driving performance in night shift workers after a normal night shift had been completed and after a normal night’s sleep on a separate occasion. It was deduced that driving following a night shift was associated with increased levels of subjective sleepiness, as well as increased eye closure and other reductions in driving performance. In a related simulator study, Horne and Reyner (1999) reported similar levels of subjective ratings of sleepiness and increased sleep intrusions evident from EEG tracings in young, experienced drivers whose sleep had been restricted or completely deprived.

WITS SLEEPINESS SCALE (WSS)

Maldonado et al. (2004) likened the determination of subjective sleepiness to the measurement of perceived pain; through the use of pictorial scales, namely cartoon faces, the assessment of perceived pain has been plausible in populations for which linguistic and numeric scales are not applicable. The WSS was validated against a

variety of different and widely accepted sleepiness scales, namely the Standford Sleepiness scale (SSS) and the Karolinska Sleepiness Scale (KSS) both of which are verbally anchored. An additional validation was completed against the Visual Analogue Scale, which measures subjective sleepiness geometrically (Maldonado et al., 2004). Within the South African mining context and research therein, the use of the WSS has been extensive, in an attempt to determine the level of perceived sleepiness in haul truck operators during morning, afternoon and night shifts (Schutte and Maldonado, 2003). The use of the WSS was part of the three-pronged study of the physical, organisational and social factors that affected driver performance. Sixty-six operators from four different mines participated. All individuals were asked to rate their perceived level of sleepiness after each hour of their shifts. It was generally found that sleepiness levels were at their highest during the night shift, particularly between 04h00 and 06h00 (Horne and Reyner, 1999; Schutte and Maldonado, 2003).

SUMMARY AND RATIONALE FOR THE CURRENT STUDY

Napping has been identified as a conceivable and reliable fatigue and sleepiness management strategy during shift work. Despite this, the recommendations surrounding its inclusion in industrial fatigue management have been hampered by methodological differences in the ways it has been researched, with the bulk of this research focusing on prescribed naps of varying lengths and timings, which have yielded differing results. Generally, there is agreement that naps that take place during the latter part of the night (if a prophylactic nap was not possible) tend to improve early morning alertness and performance, relative to no napping. Yet there are still no conclusive recommendations regarding nap length or timing during shift work. An additional concern surrounding napping is the effect of sleep inertia on performance if naps end near to or in the circadian nadir. An additional challenge to nap prescription centres on the differences between individuals and their ability to cope with the unnatural hours that shift work may present. In cognisance of these issues and in an attempt to successfully negotiate them, a flexible time frame during which individuals could chose when to nap for a short period of time was introduced, in the context of simulated night shift conditions. The objective of this study was to therefore determine the effects of this intervention, relative to no napping.

CHAPTER III

METHODOLOGY

INTRODUCTION

Napping has been found to support the natural circadian rhythm, which is known to be upset by irregular hours of work (Bonnefond et al., 2001). However, there is no “one-size-fits-all” approach with regard to nap prescription in industrial settings, and different task requirements, work settings and individual differences further complicate the implementation of naps (Blatter and Cajochen, 2007). Previous research has focused on the impact of scheduled napping schemes in both industry and laboratory settings as a means of improving alertness and therefore performance during the latter half of the night shift (Costa, 1996; Åkerstedt et al., 2001; Belenky et al., 2003; Van Dongen et al., 2003; Kubo et al., 2007). Theoretically, the introduction of scheduled napping may aid in the adaptation to shift work (Horowitz et al., 2002), particularly in the maintenance of performance requirements. Little research however has examined the effects of flexible, self-regulated napping opportunities in this regard.

It is crucial to treat each work setting differently and provide a flexible framework in which workers may practise napping. By providing individuals with a flexible time frame during which a nap can be taken, workers will choose to nap when they feel they need to. By not enforcing a nap at a certain time, it is believed that the sleep experienced may be of a better quality, which, in the broader context of the work setting and its requirements, may prove to be more effective in the attenuation of circadian-related upsets and the ensuing fatigue and sleepiness.

It is for this reason that the concept of a “flexible nap opportunity” be researched in the context of night shift work. The effect of sleep inertia however cannot be ignored, as this phenomenon has been known to exacerbate decrements in night time work and

increase accident or error occurrence immediately after napping (Tassi and Muzet, 2000).

RESEARCH CONCEPT

The primary objective of the current investigation was to assess the impact of a flexible napping scheme on the responses and performance of a group of novice shift workers during the early hours of the morning of a night shift. The concept behind the introduction of this nap during the second half of the night stemmed from the established fact that shift workers tend to experience elevated levels of sleepiness and reduced levels of alertness during this time. This refers specifically to the period between 04h00 and 06h00, a phase known as the circadian nadir or “dead zone”, during which time work accidents and incidents tend to increase, relative to other times of the working day. Since sleepiness is a product of increased sleep pressure and the natural circadian pressure for sleep, it was hypothesized that the inclusion of a flexible nap prior to the circadian nadir would be effective in reactively alleviating sleepiness relative to no nap inclusion during simulated night shift conditions. In so doing and following a 10 to 15 minute sleep inertia period post nap, early morning performance may be sustained or enhanced.

A secondary aim of this research was to investigate the impact of flexible napping on the adaptation of novice shift workers to three nights of shift work, as inferred by performance changes on the third night, when compared to the first night. Minors and Waterhouse (1981) proposed that napping serves as means of “resetting” the biological rhythms and it was theorised that a nap during the course of the night shift would aid in maintaining performance during the course of the night, while supporting the normal physiological, cognitive and psychoemotional changes and limiting any negative changes that occur during the night.

An additional focus with regard to the maintenance of performance over the three night shifts was to determine whether the nap taken during the course of the early morning would affect subsequent day sleep and the resultant impact this has on performance during subsequent shifts.

EXPERIMENTAL DESIGN

The actual data collection coincided with the university vacation. During this 12-day period, four different shift cycles were set up. Each cycle lasted three days, with each cycle being comprised of twelve subjects. Three of the shift cycles were experimental night shift cycles and one was a control day shift cycle. Ideally, it would have been preferable for the shift cycles to be longer, considering that most industries rotate on a weekly basis, but the time frame in which the subjects could participate and the data collection could be completed, was limited.

INDEPENDENT VARIABLES

In addition to the length of the shift scheme, the independent variables or conditions had to be considered carefully. In effect, the research design for this project consisted of 3 conditions. That is, there were 3 different, independent, simulated shift arrangements. These were a no nap condition, a nap condition and a day condition. Within industry, shift workers are more often than not exposed to an 8 hour shift, which entails scheduled breaks at regular intervals. Therefore, the standard night shift or no nap condition mirrored this arrangement and permitted workers to have three, evenly spaced breaks throughout the 8 hour shift, amounting to a total of 1 hour. This condition would serve as a comparison to the intervention condition (nap condition), which incorporated the inclusion of flexible napping during the latter half of the night, with no other scheduled breaks. In addition to these two night shift conditions, an additional condition was included which completed the experimental setup for each night shift cycle. This condition was part of a collaborative study which assessed the impact of booster breaks on early morning performance: this condition involved exposing subjects to brief bouts of exercise (seven minutes and thirty seconds long) each hour of the shift, with the intention of assessing the effect of this intervention, compared to the normal night shift schedule. As a means of further comparison to the night shift conditions, the final condition was a controlled day shift, which followed a similar structure to that of the no nap condition.

Napping condition

NAP LENGTH

As napping research has been plagued by methodological differences, the ideal timings and durations for night time napping are still a topic of great debate (Tietzel and Lack, 2001; Bonnefond et al., 2004; Kubo et al., 2007). Takeyama et al. (2005) suggest nap periods of between 90 and 120 minutes to facilitate the completion of one full sleep cycle. However, in the creation of the research concept, this was deemed to be too long and not practical with regard to maintaining production. In addition to this, a longer period of sleep may accentuate the effects of sleep inertia, particularly if the subject awakes near the circadian nadir (Caldwell, 2008). Shorter naps ranging from between 20 and 50 minutes have yielded positive results in terms of improving early morning alertness and hence performance (Sallinen et al., 1998; Purnell et al., 2002; Smith-Coggins et al., 2006). However, research indicates that although shorter naps have a positive effect on objective performance measures, subjective ratings of fatigue and sleepiness remain negative, and this may be because a longer nap is needed (Rosekind et al., 1994; Sallinen et al., 1998; Purnell et al., 2002). Therefore, nap length was set at 1 hour; this would potentially provide enough time for the subjects to fall asleep and facilitate some form of recuperation, but limit the extent of sleep inertia and resultant performance decrement. A further concern around the implementation of a nap longer than 1 hour was the adverse effect it might have on the subsequent day sleep.

NAP TIMING

In addition to the length of the nap, the time at which it occurs is crucial, to ensure that it coincides with when each individual is ready for sleep. This is affected by prior sleep length and quality as well as an individual's chronotype (Takeyama et al., 2002) and circadian rhythm length (Caldwell, 2001; Caldwell et al., 2008). In an attempt to aid in the transition of novice shift workers to night work, the incorporation of a reactive 1 hour nap, taken in the latter half of the night, was conceived to be the best course of action. Additionally, the inconclusive recommendations surrounding nap timing prompted the introduction of a flexible time range during which subjects could take their 1 hour nap. This time range began at 00h00, allowing for at least two hours of

work before the nap opportunity was afforded and extended until 03h00, at which point, if subjects had not chosen to sleep, they were instructed to do so. Again, this timing arrangement meant that the subjects were awakened at 04h00 and did a further two hours of work.

Shift structure and cycle

The research project spanned a total of twelve days. Within that period, there were four shift cycles, each one lasting three days. The first nine days consisted of three cycles of night shifts, and the last three days were made up by the day shift. Within each cycle, the three experimental conditions (nap, no nap and booster break) were represented. In other words, the experimental conditions were staggered over the 9 days of night shifts. For a more comprehensive outline of the staggered experimental design, refer to the Subject distribution section (p. 58) and Table III (p. 59). With regard to shift timings, these were set according to industrial standards. Generally, the night shifts in these industries begin between 22h00 and 00h00 and end between 06h00 and 08h00. A starting time of 22h00 and ending time of 06h00 was found to be most appropriate for this research as it was aligned with industrial work shift arrangements, and logistically it was most appropriate with regard to subject transport. Subjects reported to the laboratory at 21h00 for a pre shift assessment and meal provision. For the day shift, 08h00 was found to the most appropriate starting time, with the shift ending at 16h00. This was particularly important during the night-to-day-shift transition as it provided the facilitators with enough time to prepare the laboratory for the arrival of day shift workers. Subjects arrived at the laboratory at 07h00 for pre-shift activities. Tabular illustrations of the shift structures for both the night and day shifts can be seen in Appendix B.

Task requirements

Shift work is typically characterised by repetitive, monotonous and predominantly sedentary task requirements during which time the operator's level of physical activity is moderate. Given the nature of these tasks and the fact that their performance occurs during irregular hours of wakefulness, sleepiness and at times fatigue may become manifest and increase the likelihood of errors and accidents. In an attempt to

replicate the repetitiveness of such tasks, during a period in which the physiological arousal of the subjects would be kept low, the researchers explored numerous simple and tedious tasks. These included puzzle completion, board and videogame playing. All of these however, were excluded, owing the impact of the socialising which would mask the natural circadian changes over the course of the night. Additional task options included studying: this however, could not be controlled. A computer-based typing or data capturing task might have provided a means of controlling performance and could have been used as a performance measure, but logistically, twelve separate computers could not be sourced and controlled, and in any case the laboratory did not contain enough space to house them. It was finally agreed that the primary task for the duration of the shift would be a simple beading task: subjects were presented with a 1m piece of fine cotton yarn, an 8 cm piece of aculon or “tiger tail” which fulfilled the role of a beading needle, and a choice of 6 types of different coloured, medium-sized, glass beads (8/0 = 12 beads per inch). Subjects were required to self pace their beading performance, and were given the freedom to create their own designs and beading patterns. Completed necklaces were placed neatly in front of each subject and the mass of all completed work was assessed during each test battery (Station 1).

Within the context of the university setting, a repetitive, yet necessary secondary task was identified: it was a very simple packing task, in which subjects were required to place 2010 Rhodes University student handbooks and application forms into an envelope. Although there were not enough booklets for this to be the main task, it helped to keep the subjects busy, while keeping arousal levels low. Additionally, since neither of the tasks was particularly taxing, physically or mentally, it was assumed that this would not fatigue the subjects, but merely keep arousal levels low, allowing for the natural circadian rhythm to become manifest during the course of the night.

All subjects were also exposed to a test battery which was comprised of physiological, subjective, performance-based and neurophysiological measures.

Food provision

At regular intervals during the course of the night and day shifts, all subjects were provided with moderate and controlled amounts of food. These intervals coincided

with the rest break afforded to the no nap condition. These times were prior to the start of the shift (21h00) and between 23h45 and 00h00, 01h45 and 02h15 and 04h00 and 04h15 with the total break time amounting to 1 hour. During the two shorter breaks, subjects were provided with a simple standard sandwich. During the longer mid-shift break, a larger snack consisting of a standard sandwich, a 250 millilitre cup of fruit juice and a standard green apple were provided. Subjects that were not hungry at the time were permitted to order food and eat it when they were ready. Water was freely available to the subjects at all time.

The meals were provided to ensure that any changes in performance during the test battery were attributable to the irregular work hours and not necessarily to the effect of hunger. Although it is well established that night shift workers have poor appetites, limited food was likely to have a pronounced effect on the mood and general physiological performance of shift workers, which in turn would have a confounding effect on the results obtained, hence the regular feeding breaks.

Owing to the thermic effect of food on temperature, heart rate and heart rate variability responses, the exact times during which subjects were fed were noted and accounted for in the analyses of the data after testing.

Laboratory conditions

The laboratory in which the research was conducted was quiet and removed from any major sources of noise. During the night shifts, the temperature was kept fairly constant, with values fluctuating between 19 ^{o}C and 22 ^{o}C. The day shift conditions were also kept within this range with the assistance of air conditioning. In addition to this, the fluorescent lighting in the testing and working areas provided consistent light levels of ±500 lux. These variables were both important to take cognisance of, considering the impact that lower or higher levels would have on the physiological arousal of the subjects.

DEPENDENT VARIABLES

In an attempt holistically understand the effects of the different experimental conditions on the subjects in this study, a variety of physiological, neurophysiological, performance and subjective measures were applied. The logic behind the large

number of variables stems from the fact that fatigue and sleepiness become manifest in a number of different ways and therefore these phenomena cannot be indicated or measured by one measure. It was hypothesized that through this multidisciplinary approach, insights into the effects of the conditions would be achieved. In addition to this, it was hypothesized that all these variables would provide additional information about the effects of the circadian rhythm and the extent of adaptation of the subjects to the night work.

Therefore, heart rate and heart rate variability, high and low precision performance, which included response time and target deviation, simple reaction time, short term memory performance, tympanic and skin temperature, critical flicker fusion frequency threshold, saccade latency and subjective sleepiness were the dependent variables measured during the study.

Physiological measures

It has been well established that the human biological clock, located in the suprachiasmatic nucleus of the hypothalamus, governs the changes in certain physiological process such as heart rate and body temperature to name but a few (Rogers et al., 2003). These fluctuations have been correlated with changes in alertness and arousal levels, and hence performance (Rogers et al., 2003). The inclusion of heart rate and heart rate variability as well as tympanic and skin temperature measurements facilitated insights into circadian-related changes, which in turn could be used to potentially account for changes in the various performance and response measures over the course of the night shifts.

HEART RATE AND HEART RATE VARIABILITY

Heart rate (HR) and heart rate variability (HRV) were measured using the Suunto® T6 memory belts. The system consisted of a HR strap that was fastened around the subject’s chest prior to the start of the shift. HR was recorded for the duration of the shift, with the information being down loaded and analysed post-shift. Shift work has been associated with increased cardiovascular problems; this may stem from the unnatural fluctuation in sympathetic and parasympathetic system stimulation caused by the inversion of the sleep-wake cycle, particularly the decreased HRV as a product

of increased sympathetic activity (Furnal et al., 2000). Heart rate variability was processed from inter-beat-intervals in time domain (coefficient of variability) and in frequency domain, processing Low Frequency band and High Frequency band (0.04-0.15 Hz and 0.15-0.4 Hz, respectively).

TYMPANIC TEMPERATURE

Tympanic or ear temperature has been identified as accurate measures of body temperature (Barber and Kilmom, 1989; Chamberlin et al., 1995). Through the use of the Braun ThermoScan ExacTemp® Infrared Emission detection thermometer, body temperature was recorded for each subject. The thermometer was set in “equals” mode so as to measure without adding any offset (Chamberlin et al., 1995). The Thermoscan records eight measurements per second, displaying in degrees centigrade, the highest temperature.

INFRARED SKIN TEMPERATURE

An additional measure of skin temperature was made using an Infrared thermal imaging camera (Flir Systems: ThermaCAM i series). This was done in order to gain insights into the thermoregulatory reactions of the subjects to the ambient changes in temperature, particularly during the night shift, as well as the related changes in the body temperature due to abnormal periods of wakefulness, as controlled by the circadian rhythm. Skin temperature was also included because with the onset of sleep that usually coincides with an increase in sleep pressure and circadian modulation for sleep, skin temperature tends to increase as a result of the dissipation of heat from the core (Oken et al., 2006).

Performance measures

BEADING PERFORMANCE

As mentioned previously, beading was selected as the primary task to be performed during the shifts. It was also used as a performance indicator. Performance, in this case was not prescribed: subjects selected their own speed of beading/performance and therefore regulated their own stress and strain levels. Assessing performance through the amount of beads produced per hour provided insight into an individual’s

self-selected performance and the output and this was important for the interpretation of all other responses that reflected strain/fatigue reactions.

SHORT TERM MEMORY PERFORMANCE

The effects of shift work and the resulting fatigue have also been associated with cognitive slowing and a reduced attention capacity. Short term memory (STM), like most cognitive processes, has been seen to exhibit fluctuations that are parallel with circadian rhythm changes, specifically core body temperature (Johnson et al., 1992) STM performance is poorest when body temperature is at its lowest. Further correlations have been made between STM, subjective alertness and sleep loss (Wright et al., 2002). For the purpose of this research, a simple word recall test was utilised

The word recall test involved the memorization of 12 words over 30 seconds, with a 5 second delay being enforced before the subjects were required to start recalling as many words as they could (Appendix B). The task took the form of a pencil and paper test and was scored by the correct number of words recalled.

SIMPLE REACTION TIME

Sleep deprivation and sleep loss as a result of shift work have been associated with increased impairment of cognitive functions (Phillip et al, 2004) and simple reaction time measures have been used as a sensitive measure in the assessment of these effects.

Within the parameters of this study, simple reaction time was assessed using a computer-based test. Subjects were instructed to respond as quickly as possible to the presentation of a large yellow circle (r = 150mm) on a dark green background, by clicking a computer mouse. The presentation of the stimulus was random, with presentation time varying between 1000 and 2000 milliseconds, so as to prevent any anticipatory effects. The programme was set up such that the first trial was always excluded from the results it provided so that if the subjects reacted particularly slowly to the first stimulus presentation, it would not confound the results. Subjects were exposed to 10 stimuli thereafter and the test took no longer than 25 seconds. If subjects committed an error of commission, and reacted prematurely to the

presentation of the stimulus, that trial was not considered in the final results. The computer programme accounted for this lapse by including an additional trial. Another exclusionary criterion for this test was a reaction time of greater than 1000 milliseconds.

PRECISION TASK PERFORMANCE (MODIFIED FITTS TAPPING TASK)

Within many industrial tasks, the requirement for accuracy and precision in task completion is essential to ensure a product of the highest quality. As such, two precision-based tests were included in the study to monitor changes in response time and precision performance. Two precision tasks were devised and utilised in the current study, both of which were based on Fitts' Law, which states that the time required to rapidly move to a target area is directly affected by the distance to be moved and the size of the target (Fitts, 1954). For the high precision tapping task, the target size changed with target distance so that the index of difficulty was 5.66 constantly while the low precision task was set at an index of difficulty of 3.66. During both tasks, which were performed on a touch screen, 25 yellow spherical targets appeared randomly and in an uninterrupted manner on a work field that spanned 220 x 200mm. Subjects were instructed to select the target with their index finger as quickly and accurately as they could. The delay between the presentation of each target varied between 500 and 1000 msec. The test took roughly 40 seconds to complete. Exclusionary criteria for this test included the incidence of double tapping, a response time of greater than 1.5 seconds and a target deviation of greater than 100 millimetres. The program accounted for these errors by including additional trials. The first trial was also not included in the final analysis.

SACCADE LATENCY

Fatigue and sleep deprivation have been associated with an increase in saccade latency (Zils et al., 2005) and more generally, most oculomotor functions have been found to be negatively affected by sleep deprivation and sleep cycle inversion. It is for these reasons that saccade latency, in conjunction with precision task performance, was incorporated into the study.

Within the context of this research, the use of the Dikablis Eye tracker aided in the assessment of saccade latency, specifically prosaccade latency. The eye tracker was fitted to the head of the subject, with the weight of the entire unit being supported by the nose support, and secured with an elastic retaining band that was placed around the subject's head (Robertson, 2009). It used two different cameras to aid in the assessment of saccade performance.

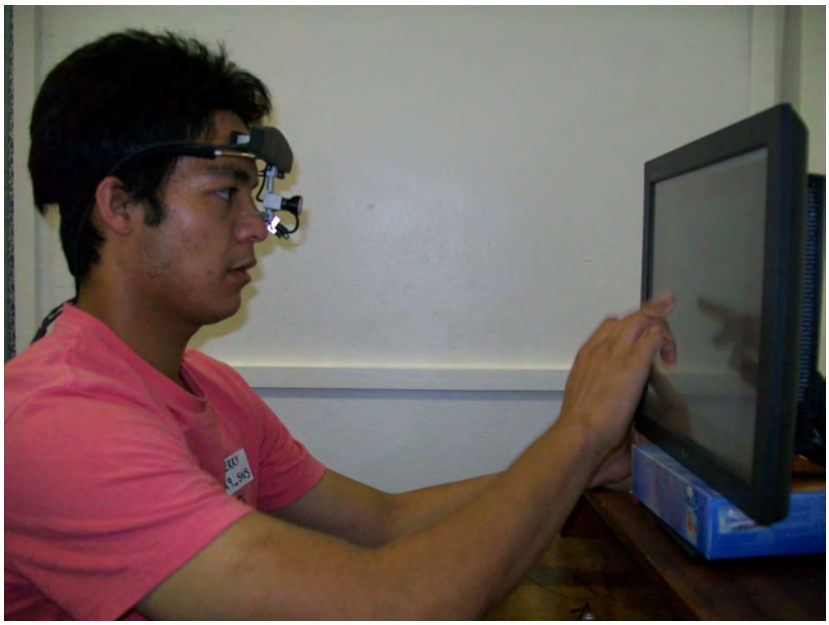

Figure 2: The Dikablis Eye Tracker fitted to a subject while performing one of the modified Fitts tests.

Over time, the eye tracker monitored the movement of the pupil, providing researchers with insights into how long it took the eye to respond (through movement) to the presentation of a stimulus, in this case, the appearance of the different sized yellow targets during the two precision tasks (Refer to precision measures section above). The field camera monitored the direction of the subject's gaze by detecting the cornea reflex, subsequently recording changes in the field of view. The unit, in its entirety, transferred the images captured from the left eye only, to a recording unit, which digitised the analogue PAL signals in real time and saved it to a hard disc (Robertson, 2009).

CRITICAL FLICKER FUSION FREQUENCY (CFFF)

The determination of the ascending CFFF threshold was incorporated into the test battery because of the established fact that CFFF is directly affected by an individual's natural circadian fluctuations, as well as accumulated fatigue and reduced arousal levels that can potentially result from extended or atypical work periods (Matsumoto et al., 1978). The ascending threshold of CFFF was determined and included with the intention of attempting to ascertain whether the inclusion of the flexible nap would have an impact on the threshold, following circadian rhythm upsets during the night shift. A pair of bifocal binoculars was modified into the CFFF apparatus and the ascending threshold of CFFF was measured. The binoculars were designed in such a way that each lens was covered and fitted with a light-emitting diode (LED) that produced a white light. Only the right LED was operational and the viewing angle was 90°.

Subjective measures

SUBJECTIVE SLEEPINESS: KAROLINKSA SLEEPINESS SCALE (KSS)

The KSS is a well established 9-graded, verbally anchored scale used as measure of instantaneous sleepiness with the following ratings: 1 = very alert, 3 = alert, 5 = neither alert nor sleepy, 7 = sleepy (but not fighting sleep) and 9 = very sleepy (fighting sleep) (Appendix B) (Maldonado et al., 2004). The KSS was used to determine the subjective sleepiness of the subjects at regular intervals throughout the night. It was included because it is easy to apply and because it provides an immediate and clear indication of subjective sleepiness. It was also assumed that the subjects participating in the study had a high level of literacy and therefore would be able to comprehend the statements within the scale.

WITS SLEEPINESS SCALE (WSS)

In addition to the KSS, a pictorial measure of subjective sleepiness was used: the WSS (Appendix B) is a validated scale that uses five cartoon faces of differing levels of sleepiness, as a measure of subjective sleepiness (Maldonado et al., 2004). The use of cartoon faces has previously been very successfully applied in measurement of perceived pain amongst groups for whom the use of geometric and semantic scales is

unsuitable (Maldonado et al., 2004). The WSS was chosen for its ease of application and interpretation.

NINE-DAY SLEEP DIARY

In addition to the actual measurements taken during the course of the testing, subjects were presented with and asked to complete a nine-day sleep diary as accurately and as honestly as possible. The diary prompted each subject to complete the required fields for the three days before testing began, the three days of testing and the three days after testing had been completed. As illustrated in Appendix A, the sleep diary probed the extent of wakefulness and sleepiness, sleep and waking times and the duration of sleep during this period.

In addition to this information, the sleep diary required the subjects to record any activities they performed outside of the laboratory, which may have negatively affected their recovery sleep between the shifts. These included the consumption of alcohol, caffeinated drinks and medication of any kind, exercise and napping. 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 group, determining the duration and perceived quality of the recovery sleep was an important result, when compared to the no nap condition. This was because napping during the work shift has been known to result in a reduced recovery sleep during the following day.

Subject assessments

ANTHROPOMETRIC AND BIOGRAPHICAL INFORMATION

Basic anthropometric and biographical data were acquired. Each individual's age and gender was recorded. The race of the subjects was also recorded. Again, race was considered regarding the randomisation of the sample groups, but it was not a dominant factor in the randomisation process: this was done to ensure that any cultural diversity would not affect the responses of the subjects. The groups would also represent the diversity in the South Africa work force as well.

SUBJECT CHARACTERISTICS

Thirty-six student volunteers - 18 males and 18 females - were recruited to participate in the current study between the ages of 18 to 26 years. The limited age range was selected due to the fact that with increasing age, circadian and sleep-related physiology is known to change and this may impact the results obtained in the study. In addition to this, a large percentage of the South African working population fall within this age range. However, the disadvantages of restricting the age of the subjects meant that any results obtained could not be applied to older age groups.

All the subjects were sourced from the university student population, as this was the population available for testing. Moreover, this sample did not have any experience with shift work which meant that the results obtained would not be biased by any prior experience of atypical work schedules.

Table I**:** Subject anthropometric and biographical data

MEASURES	**MALES**	**FEMALES**
Stature (mm)	1735.1 ±53	1539.5 ±35
Mass (kg)	62.4 ±8.5	60.3 ±11.3
Age (years)	21.4 ±1.46	20.5 ±1.29
Education (years)	13.5 ±1.5	13.4 ± 1.1

CHRONOTYPE

Each subject was required to complete an adapted version of the Morningness-Eveningness Questionnaire (MEQ) (Horne and Ostberg, 1976, Appendix A). The MEQ consists of 19 questions or statements, concerned with discerning an individual's preferred rising and bed times, favoured times for exercise and mental performance and the extent of subjective alertness before and after sleep. The questionnaire produces scores that range between 16 and 86, with higher scores being associated with morningness, lower scores with eveningness. There are further subcategories,

namely definite morning and evening types (70-86 and 16-30 respectively), moderate morning and evening types (31-41 and 59-69 respectively) and an intermediate type (42-58).

The inclusion of this questionnaire aided the researchers in evenly distributing different chronotypes across all three conditions, thus ensuring that the results obtained would not be confounded by one particular chronotype. Chronotype was also used as a covariate during statistical analyses in order to determine any dependencies to the responses obtained. The breakdown of this distribution is illustrated in Table II.

Table II**:** Distribution of chronotype and gender by condition (12 subjects per condition)

	Napping group (%)	**No Nap group (%)**	**Day group (%)**
Morning type	0	0	0
Moderate Morning type	25	25	8
Intermediate	67	67	84
Moderate Evening type	8	8	8
Evening type	0	0	0
Males	50	50	50
Females	50	50	50

STATISTICAL HYPOTHESES

With the inclusion of a flexible napping scheme during night shift work in the context of the current study, the following was expected:

- Napping would have an effect on the performance and response measures, relative to no napping.
- Napping would have an effect on the habituation of the subjects over the three days regarding performance and responses.
- Nap inclusion would evoke differential effects on the circadian-related changes for all measures, relative to the no nap condition.

The statistical hypotheses were as follows:

Hypothesis 1:

The null hypothesis (H_o) proposed that there would be no differences in the responses to all variables between the nap and no nap conditions during the course of the night shift cycle:

a)

H_o: $\mu PARA(\text{General condition level})_{nap} = \mu PARA(\text{General condition level})_{no\ nap}$

H_a: $\mu PARA(\text{General condition level})_{nap} \neq \mu PARA(\text{General condition level})_{no\ nap}$

b)

H_o: $\mu PARA(\text{Final condition level})_{nap} = \mu PARA(\text{Final condition level})_{no\ nap}$

H_a: $\mu PARA(\text{Final condition level})_{nap} \neq \mu PARA(\text{Final condition level})_{no\ nap}$

“PARA” refers to all parameters or variables assessed in the study.

“Nap” refers to the condition in which the one hour nap was included and the effect that this intervention had on each parameter and its interaction with Day and Time effects.

“No nap” refers to the standard night shift condition without a nap and the effect that this had on each parameter and its interaction with Day and Time effects.

The effect of napping can be expressed in one two ways: “General condition level” (a) refers to a general condition effect over the whole three-night shift cycle. “Final condition level” (b) refers to the effect of the condition on during the third night shift only. A detailed explanation of these effects is explained at the start of Chapter IV.

Hypothesis 2:

The null hypothesis (H_o) proposed that there would be no differences in the habituation of the sample, as indicated by changes in the responses to all variables over the three night shifts, between the nap and the no nap condition.

$$H_o: \mu PARA(Day)_{nap} = \mu PARA(Day)_{no\ nap}$$

$$H_a: \mu PARA(Day)_{nap} \neq \mu PARA(Day)_{no\ nap}$$

“Day” refers to the factor of “habituation”, specifically whether the subject responses changed over the course of the three night shifts, as a product the two night time conditions

Hypothesis 3:

The null hypothesis (H_o) proposed that there would be no differences in the circadian-related changes in the responses to all variables between the nap and the no nap condition.

$$H_o: \mu PARA(Time)_{nap} = \mu PARA(Time)_{no\ nap}$$

$$H_a: \mu PARA(Time)_{nap} \neq \mu PARA(Time)_{no\ nap}$$

“Time” refers to the impact of circadian-related factors on the responses of each parameter during each night shift and the effect that napping induced on these responses, compared to the no nap condition

SECONDARY EFFECTS OF INTEREST

In addition to the abovementioned primary hypotheses, the effect of chronotype and condition on subject responses was also considered. Furthermore, the effect of the different conditions on the extent of fatigue and recovery experienced by the subjects during and between the shifts was also analysed. In this case, it was referred to as the rollover effect. Other effects specific to the nap condition were also explored, specifically the presence and effects of sleep inertia. Lastly, the length of the recovery day sleep was also compared between to the conditions to determine whether or not the nap negatively affected this.

The following measures were included in the current study:

Physiological responses:

- Tympanic temperature
- Skin temperature
- Heart rate frequency
- Heart rate variability
- High frequency power
- Low frequency power
- Low frequency/high frequency ratio

Performance indicators:

- Beading performance
- Low and high precision response time
- Low and high precision target deviation
- Simple reaction time
- Simple word recall memory test

Neurophysiological measures:

- Saccade latency (high and low precision)
- Critical flicker fusion frequency

Subjective measures:

- Karolinska Sleepiness Scale
- Wits Sleepiness Scale

EXPERIMENTAL PROCEDURE

Subjects

Additional criteria had to be met in order for subjects to participate in the research. These criteria included:

Non smokers: smoking and the substances contained in cigarettes are known to have a stimulating effect which could potentially “mask” the endogenous circadian rhythm (Blatter and Cajochen, 2007) and for this reason, smokers needed to be excluded.

No prior shift work experience: experienced shift workers may be able to adapt more easily to night shift work which may confound the results of other subjects that are novices.

No sleep-related disorders: sleep disorders may negatively impact night time performance due to the build up of sleep pressure and the resulting circadian upset caused by sleep disorders. In additional to this, individuals whose failure to sleep during the napping period as a result of an underlying sleep disorder, may produce results that are misleading.

No regular consumption of alertness enhancing medications: alertness enhancing compounds such as caffeinated drinks and compounds containing amphetamines have been associated with improvements in neurobehavioural functioning and alertness (Pigeau et al., 1995; Rogers et al., 2003). However, in this particular research project, it was believed that regular intake of these substances would hinder the natural progression from alertness to drowsiness throughout the night shifts and for this reason, individuals who regularly consume these substances needed to be excluded from the study.

Good physical health: night shift work has been associated with a reduction in general wellness due to the unnatural hours during which workers are awake. Individuals who are already sick would potentially worsen their sickness, by compromising their immune function if they engaged in this form of research. Those in this position were therefore not permitted to take part in the study. A regular sleeping pattern of between 7 and 8 hours per night was also one of the criteria for inclusion.

Subject distribution

Each independent 3-day cycle was composed of 12 subjects. The number of subjects allocated to each condition was based on the number of subjects that the facilities and test battery could handle at any one time. It would have been preferable to have more subjects, but logistically this was not possible. Following the interpretation of the Morningness-Eveningness questionnaire and the consideration for gender, the researchers randomly assigned each subject to one of the three conditions (napping, no napping or the day shift). For each night shift however, the 12 subjects were evenly

distributed across three different conditions, namely no nap condition, a nap condition and “booster break” condition. The booster break condition formed part of a collaborative study that focused on the impact of light exercise each hour on night time performance.

This arrangement was the same for all 3 night shift cycles and therefore, over the 9 days of night shifts, 12 subjects per condition were assessed. All twelve subjects during the day shift condition served as a further comparison to both the napping and booster break studies: this meant that neither of the experimental conditions was included during the day shift.

Table III**:** Illustration of shift arrangements and subject distribution amongst the different conditions. (Shift cycles = refers to the staggered design of the experimental groups (the night shifts) and the control group (the day shift) over the twelve days of testing. NC = the Nap condition, NN = the No nap condition, BB = the Booster break condition. Note: the Day shift contains 12 subjects that made up the control group and followed the same shift arrangement as the no nap condition.

	Duration = (Days)	**Type of shift**	**Number of Subjects**	**NC**	**NN**	**BB**
Shift cycle 1	3	Night	12	4	4	4
Shift cycle 2	3	Night	12	4	4	4
Shift cycle 3	3	Night	12	4	4	4
Shift cycle 4	3	Day	12		12	

The inclusion of three conditions within each night shift cycle was done so that any differences in ambient temperature or working conditions could be accounted for.

Habituation

The current study consisted of three separate sessions, namely two habituation sessions followed by a three day testing session. Informed consent was obtained following the first habituation session (held in the Department of Human Kinetics and Ergononimcs). The initial session was held to familiarise all the participants with experimental protocol, all procedures and all equipment to be used (Appendix A). Subjects were also informed of certain controlled parameters that they would have to adhere to prior to and during the course of testing (Appendix A). All participants’

biographical data were measured and recorded. Each individual was also required to fill out the Morningness-Eveningness Questionnaire (see Appendix A). Subjects were asked to report to the testing laboratory for the second habituation session.

For the second habituation session, the subjects were shown around the laboratory (Biopaharmaceutics Research Institute Laboratory, BRIL) where the experiments took place. Areas of particular importance were the napping and recreational areas, as well as the working and testing areas. Following this, all subjects were given the opportunity to practise the tasks that had to be performed, namely the beading and packing. Subjects were also exposed to the entire test battery so that they would become familiar with the requirements of each station and the correct ways in which each test within each station had to be performed and accurately completed. Each subject was presented with the 9-day sleep diary (Appendix A), and were asked not to sleep or nap during the day before their first night shift to ensure that normal homeostatic sleep pressure would build up, and that the effects of circadian disruption would become manifest as it would in normal work life.

Ethical considerations

Prior to the recruitment of any subjects, all researchers involved in the project completed the required formal Ethical application, as per the requirements of the Human Kinetics and Ergonomics Departments Ethics committee.

INFORMED CONSENT

Prior to the commencement of the study all recruited subjects were made familiar with the research requirements, the potential risks and benefits, which were explained both verbally and in written form (Appendix A). Subjects were then given the opportunity to sign an informed consent document. Throughout all the interaction that the researchers had with the subjects, a constant reminder was made that all subjects were free to withdraw from the study at any stage, with no prejudice against them. Subjects that agreed to be part of the research were assured that all of the personal information gathered during the course of the research would be kept confidential and that their anonymity would be maintained. All subjects were remunerated at a normal

rate and in the cases where subjects withdrew from testing prematurely, compensation was made for the hours performed up until this point.

ANONYMITY

All data and personal information recorded during the study was stored in either electronic or paper format, with each subject's data being assigned a code specific to the condition to which they were assigned. All data was stored on personal computers of the researchers involved, and removed off any communal research laptops. Only the primary researchers kept the main lists of codes and names. Following the completion of the data reduction and interpretation, all subjects were notified via email of a voluntary feedback session specific to the condition in which they participated.

Commencement of shift

Subjects were instructed to arrive at the laboratory at 21h00, 1 hour prior to the start of the night shift. On arrival, each subject was fitted with the heart rate memory belt. A standard pre-shift meal was provided. From 21h15 onwards, testing groups were exposed to the test battery every 15 minutes, and at 22h00, the shift commenced. For the day shifts, subjects were asked to report to the laboratory at 07h00, and the same pre-shift protocol was followed as was done for the night shift components. The shift commenced at 08h00.

Task performance

Throughout the 8 hour work shift all subjects were required to perform two tasks. The primary task, and the one that the subjects spent the bulk of the 8 hours completing was a very simple beading task. All subjects were instructed to use the materials that were provided to them (beading needle, beads and 1 metre thread) and produce necklaces of beads of their own design. Subjects were instructed to bead at a constant but self-paced rate and at the commencement of each test battery, all bead work was weighed and from this mass, the total number of beads produced per hour was calculated. In addition to this, the simple packing task was also performed, where each hour, subjects were required to pack no more than five application packs, which took them no longer than between five and seven minutes.

Break schedules

NO NAP CONDITION

At regular intervals throughout the night, the no nap condition subjects were provided with a break opportunity (Appendix B), which they took in a separate recreational room removed from the main testing area. The two 15 minute breaks were scheduled to occur at 23h45 and 04h00 respectively, while the mid-shift 30 minute break was scheduled to happen at 01h45. The subjects were provided with their snacks, while they sat quietly and read magazines provided or socialised under the supervision of a research assistant. Subjects that were falling asleep were gently awoken through name calling. In total, the no nap group subjects had a 1 hour break through the course of the night.

NAP CONDITION

Subjects were provided with dormitory-like nap areas, with males and females being separated. Ideally, it would have been preferable for each subject to have his/her own room, but due to the infrastructural restrictions, subjects (no more than two at any one time) had to share a room, as seen in Figure 3. This communal type of nap area resembled the structure of *in situ* nap areas, similar to the communal “green areas” where workers would take breaks. The rooms were dark and quiet, and removed from the working area so that any noise from the other subjects would not disturb the napping subjects.

The subjects that had been placed in the nap group were provided with the opportunity to take a nap from 00h00 until 03h00. While the no nap group subjects took their breaks in the recreational room, the napping subjects were provided with their snacks while they continued working. At any point at which subjects wished to nap, a pre-nap test was administered and subjects were sent to the napping area. If subjects went to nap at different times, the researchers ensured that a minimal amount of noise was made when entering the napping area.

Figure 3: The dormitory-type napping area (Clean linen was provided for each subject).

After one hour, the researcher woke the subjects by quietly calling their names. In most cases this was enough to wake the subjects. In instances where subjects did not wake up with name calling, the researcher gently motioned the subjects until they awoke. All the subjects were provided with the opportunity to gather themselves, before returning to the testing area and carrying out the post-nap test battery.

STANDARD DAY SHIFT (CONTROL CONDITION)

The Standard Day Shift (SDS) followed much the same structure as that of the SNS in that subjects were provided with two 15 minute breaks taken at 09h45 and 14h00 respectively, with the mid-shift 30 minute break being provided at 11h45. The food arrangements and conditions during the break were the same as those during the no nap group during the night shifts.

Test battery

Each group of twelve subjects was also randomly assigned to a specific test group. There were three separate test groups, each one consisting of four subjects. With regard to the randomisation of these groups, chronotype, gender and condition were considered, which ensured an equal distribution of the abovementioned factors. Subjects were made aware of which testing group they were in prior to the start of the pre-shift test battery. Each subject was also assigned to one of four testing stations. Subjects were instructed to start at that same station each time they entered the testing area. At each station, all tests were performed by the same researcher for all

subjects throughout the study. Appendix B shows a detailed breakdown of the test battery arrangements for each condition.

It took a total of 45 minutes for all three testing groups to complete the test battery. Therefore, each group was afforded 15 minutes to complete the test battery. Test 3 (02h15 to 03h00) was excluded from all analyses, as many of the nap condition subjects chose to sleep during this test. Therefore no data were available to compare to the no nap group during this period.

Table IV**:** Test timings during the night and day shifts

	Start of test interval		**End of test interval**	
	Night	**Day**	**Night**	**Day**
Test 1	22h15	08h15	23h00	09h00
Test 2	00h15	10h15	01h00	11h00
Test 4	04h15	14h15	05h00	15h00
End of shift test	05h45	15h45	06h30	16h30

STATION 1: SIMPLE REACTION TIME, SUBJECTIVE SLEEPINESS AND MOOD STATE ASSESSMENT

At station 1, all subjects began their assessment with a subjective rating of sleepiness, specifically the Wit Sleepiness scale (WSS). The WSS was fixed to the testing area and subjects were instructed to point to the face that best depicted how they felt at that particular time. To prevent any bias/leading effects, subjects were not permitted to see their previous responses.

After the WSS rating, subjects were asked to verbally rate their level of sleepiness using the KSS. All previous responses were not displayed, so as to avoid any leading effects. The simple reaction time test followed this shortly thereafter.

STATION 2: BEADING PERFORMANCE ASSESSMENT, CRITICAL FLICKER FUSION FREQUENCY (CFFF), INFRARED SKIN TEMPERATURE (IST) AND TYMPANIC TEMPERATURE (TT)

On arriving to this station, subjects were asked to bring with them all the beading work that they had done up to that point. The beads were then weighed on a Digital Platform scale, which had a weight threshold of 1 g.

Following this, the CFFF threshold was determined. Subjects were asked to place the binocular apparatus over their eyes, as seen in Figure 4, so that no ambient light could confound the measurements. Subjects were to instruct the researcher verbally when they could no longer perceive a flicker. The researcher turned the dial at a rate of 1 Hertz per second until this stage was reached. Then the researcher manipulated the frequency 1 to 2 Hertz around this Hertz value to determine the exact point at which the steady light was perceived.

Figure 4: Subject performing the CFFF test

On completion of the CFFF, the Infrared skin temperature was recorded. This was achieved with the use of the IPR infrared camera. All subjects were instructed to sit still when the camera was being used. The camera was aimed at the subject's forehead, at a constant distance of ±15 cm for all subjects and a thermal image was

recorded. This image provided an indication of the temperature of each subject's forehead. This was repeated and an average was taken between the two values. This test took no longer than ten seconds to complete. Finally, each subject had his/her tympanic temperature taken using the Braun tympanic temperature probe. For hygiene purposes, the probe was covered with a new lens cover for each subject.

STATION 3: SACCADE LATENCY AND PRECISION PERFORMANCE (HIGH AND LOW)

On arrival at the station, each subject was fitted with the Dikablis Eye Tracker. Before the test, the researcher responsible ensured that the eye and field cameras were correctly positioned. Subjects then performed the two precision tasks. Subjects were required to respond as rapidly as possible to the presentation of the yellow circles that changed position on the screen, with the order of the high and low precision tests being randomised.

STATION 4: SIMPLE WORD RECALL MEMORY ASSESSMENT

Subjects were presented with 6 word pairs and given 30 seconds to memorise them. Following this, a 5-second delay was introduced before the subjects were permitted a further 30 seconds to recall as many words as they could, in no particular order. Once this had been completed, subjects were presented with a different set of 6 word pairs and the same procedures were applied. The test score was the number of correct words recalled. The score for a particular test battery was the average of the two tests. 36 different cards were created and each subject was exposed to the same two cards during each test. These were then put to one side and a new set was used. This ensured that the subjects saw each group of words once. All subjects within a particular test battery were exposed to the same two sets of words, to ensure comparability. Following the completion of all four stations, subjects returned to their work stations and carried on with the packing and beading tasks.

Post shift

On completion of the post-test battery, the last of which ended at 06h30, subjects were free to return to their homes and encouraged to sleep for a minimum of 5.5 hours. Since the subject group came from very different parts of the community, it was

difficult to monitor sleep times. Accordingly, subjects were reminded to record their sleep and wake activities in their sleep diaries and report to the laboratory at 21h00 that evening. Subjects that formed part of the day shift group left the laboratory at 16h30 following post-test battery completion and were also reminded to adhere to the necessary requirements of the study and complete the required sleep diary information.

Statistical procedures

Prior to any statistical analyses, all data were referenced to the individual measures taken during the first three tests of the first shift, prior to inclusion of the nap as the intervention. The reasoning behind this was to eliminate different individual levels of response that would add irrelevant variance to the data. Therefore, all data (except when indicated otherwise) reflected a ratio to these initial values. The trends observed for this referenced data did not differ from those of unreferenced data. Additionally, the individual variance was normalised to the average variance of each group, thereby ensuring that each individual had a similar impact on the results, irrespective of individual-specific major or minor responses. This was achieved by adapting the concept of a z-transformation to this type of setting.

All results were then analysed using the Statistica software package Version 8 (Statistica©, Statsoft Inc). Initially descriptive statistics were run on all data to test for normality and furthermore obtain mean and standard deviation of responses for all conditions. Two and three way ANOVAs were conducted for all the variables for the two night time conditions only (no nap and nap) to determine the general effects of the independent variables (a detailed explanation of these effects can be found in the Key considerations for statistical interpretation, p. 69). Further analysis considered chronotype as a categorical covariate. This was performed in an attempt to understand the effects that the different conditions had on the responses of subjects with different chronotypes. Therefore a condition and chronotype interaction effect was analysed using a three way ANOVA with chronotype as a covariate. All statistical responses were set at a confidence interval of $p \leq 0.05$. In instances where there was a significant difference between the two conditions, in that napping evoked an effect, a further comparison was made to the responses of that variable during the day shift.

CHAPTER IV

RESULTS

INTRODUCTION

The primary aim of this investigation was to assess the impact of a 1 hour flexible nap opportunity on performance indicators and physiological, neurobehavioural and subjective responses during simulated night shift conditions, when compared to a no nap condition. An additional objective was to determine whether the nap intervention would help to maintain or improve performance (cumulatively) over the three night shifts, when compared to the no nap.

Data collection for this study was carried out over a period of twelve days. These days were divided into four, three-day shift cycles. Three of these cycles were night shifts, and one was a day shift and each cycle was comprised of twelve subjects. As regards the night shift, the twelve subjects were distributed evenly amongst three experimental conditions, namely a nap condition and a no nap condition that formed part of this study, and a booster break condition that formed part of a collaborative study. Subjects were required to perform simple beading and packing tasks over the 8hour shifts and were assessed at regular intervals. Subjects in each condition were afforded breaks of different kinds that amounted to one hour: breaks took the form of either a nap or a rest break.

The test battery that each subject was exposed to provided insights into circadian-related changes and the subjective impact of the various conditions, which could in turn be linked to fluctuations in each subject's performance. These included: simple reaction time, a simple word recall memory test, high and low precision response time and target deviation tasks and beading performance. From a physiological perspective, heart rate and heart rate variability, tympanic and skin temperatures were recorded. Neurophysiological assessments included prosaccade latency and the ascending threshold of Critical flicker fusion frequency. Finally, subjective

assessments of sleepiness were measured by the Wits and Karolinska Sleepiness Scales, which completed the test battery.

Key considerations for statistical interpretation

In an attempt to explain the complex effects evoked, the italicised words will refer to the following:

- *General effects:* refers to the statistical tables displayed in the proceeding text, where all data during tests 1, 2, 4 and the End of shift test for both conditions, were analysed using a three-way Analysis of Variance:

    - *Condition effect:* refers to the observed significant differences between the two conditions (nap compared to no nap) over the course of the three night shifts. This excludes the effect of the circadian rhythm and purely illustrates the effect of the different conditions on the subject responses.

    - *Time effect:* refers to the observed significant differences between the different times of testing (measures) over the course of the night. This is assumed to be the product of the natural circadian oscillations and the associated physiological fluctuations. This effect is irrespective of condition.

    - *Day effect:* refers to the observed significant differences between the different night shifts, indicative of the subjects adapting or habituating to the irregular work schedule: this effect becomes manifest through changes in responses over the course of the three-day shift cycles. This effect does not include the effect of the condition.

    - *Condition by Time effect:* refers to the observed effects of the different conditions on the circadian-related fluctuations in the responses of the subjects during the different tests over the course of all three night shifts.

- *Condition by Days effect:* refers to the observable effects of the different conditions on the extent of adaptation of the subjects, as illustrated through the changes in subject responses over the three night shifts.

- *Final effects:* refers to the observed significant differences in responses between the two conditions during the third night shift only. It is assumed that differences between the conditions would have accumulated over the course of the three-night shift cycle. This was analysed using a two way Analysis of Variance.

- *Chronotype by Condition:* refers to the way in which subjects with different chronotypes responded to the two different conditions. This was performed by through a three-way ANOVA, with chronotype considered as a covariate. However, only the chronotype interaction effect with the two conditions (Condition by chronotype) was considered for interpretation.

- *Roll-over effect:* refers to the observed "roll-over" effects of the previous night time's shift and the activities therein on the subsequent shift's performance and responses. Firstly, the difference between the End-of-shift and pre-shift tests was calculated to indicate a *fatigue effect* over the work shift, which demonstrated a deterioration in performance and responses over time.

  Secondly, a comparison was made between the pre-shift responses on Day 2 and 3, compared to the End-of-shift responses of the previous day. This would indicate the extent of recovery (*recovery effect)* occurring during the shift break. A two-way ANOVA was used in these analyses, with the two variables considered being condition and days.

Table V**:** Statistical table key, indicating which statistical methods were used to determine the following effects

	Effect	Statistical method of Analysis
GENERAL EFFECTS	**Condition**	3 way ANOVA
	Days	
	Days*Condition	
	Time	
	Time*Condition	
	Days*Time	
	Days*Time*Condition	
CHRONOTYPE EFFECT	**Condition*Chronotype**	Covariate for 3 way ANOVA
FINAL EFFECT	**Final**	2 way ANOVA
ROLL-OVER EFFECT	**Fatigue**	2 way ANOVA
	Recovery	2 way ANOVA

PERFORMANCE MEASURE

Beading performance

Beading performance was assessed by measuring the mass of beads used per hour during each subject's necklace work. This was calculated by determining the number of beads used between the test batteries (Test 2 – Test 1, Test 4 – Test 2) and dividing this number by the time period between the different tests. An important consideration was that the subjects were permitted to self pace their performance.

With regard to *general effects,* there was a significant effect of *condition* on beading performance (p=0.03; Table VI): the nap group produced significantly more beads over the three shifts, particularly over the second and third nights, when compared to the no nap group. A significant *day effect* demonstrated that the output increased over the three shifts as well. A significant *time effect* illustrated the effect of the circadian rhythm on beading performance; Figure 5 displays the impact of this circadian fluctuation on the no nap group, where performance, particularly during shifts two and three decreased consistently over the course of the night. The nap condition evinced the same decrement initially. After the nap however, performance improved.

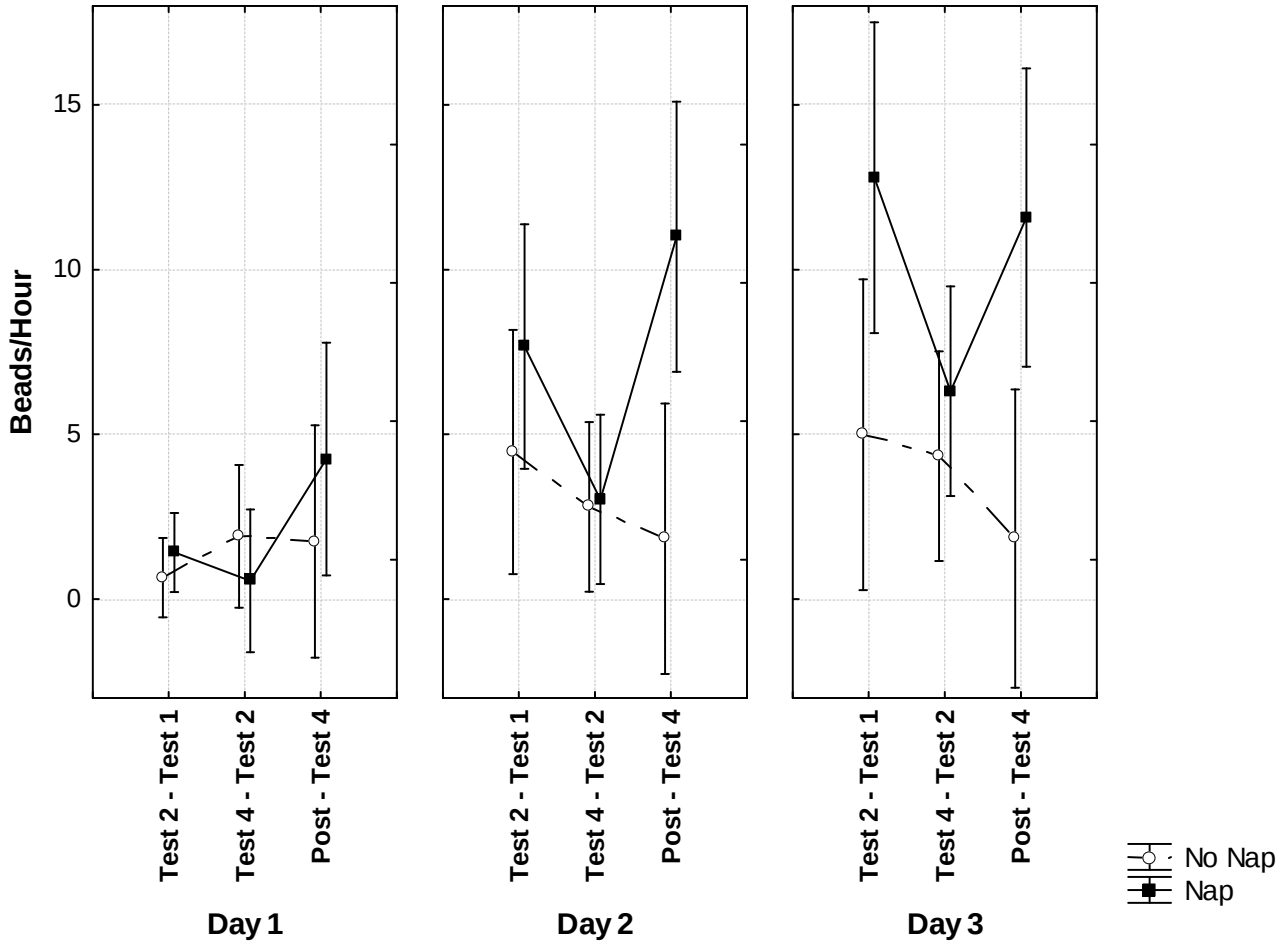

Figure 5**:** Beading performance over the three night shifts.

An interaction effect between *time* and *condition* was found: the no nap group tended to perform better in the earlier half of the night and deteriorate near to the end of shift, whereas the nap group maintained and improved performance over the entire shift cycle. This demonstrated the effect of the nap on the circadian-related decrements that are known to affect alertness and therefore performance. Additional analyses revealed that there was also a significant *final effect,* in that the nap group produced more beads over time than the no nap group, particularly during the third night shift.

Table VI**:** Statistical effects for beading performance (* denotes a significant effect).

	SS	Degrees of freedom	MS	F	p
Condition	772	1,22	771.961	5.269	0.032 *
Days	1009	2,44	504.336	15.562	0.000 *
Time	231.8	3,66	115.885	4.918	0.012 *
Days*Condition	314.7	2,44	157.335	4.855	0.012 *
Time*Condition	423.8	3,66	211.888	8.993	0.001 *
Days*Time	158.2	6, 132	39.56	3.534	0.01 *
Days*Measures*Condition	66.42	6, 132	16.606	1.484	0.214
Condition*Chronotype	146.4	2,44	73.206	0.473	0.63
Final	570.4	1,22	570.375	9.972	0.005 *

The significantly higher beading rate for the nap group, compared to the no nap group prompted a further comparison with that of the day shift. The nap group produced significantly more beads per hour than either of the other two conditions over the three days of testing. Further analysis revealed that there were however no significant differences between the no nap group and the day group (p = 0.697) (Appendix C, Table 1).

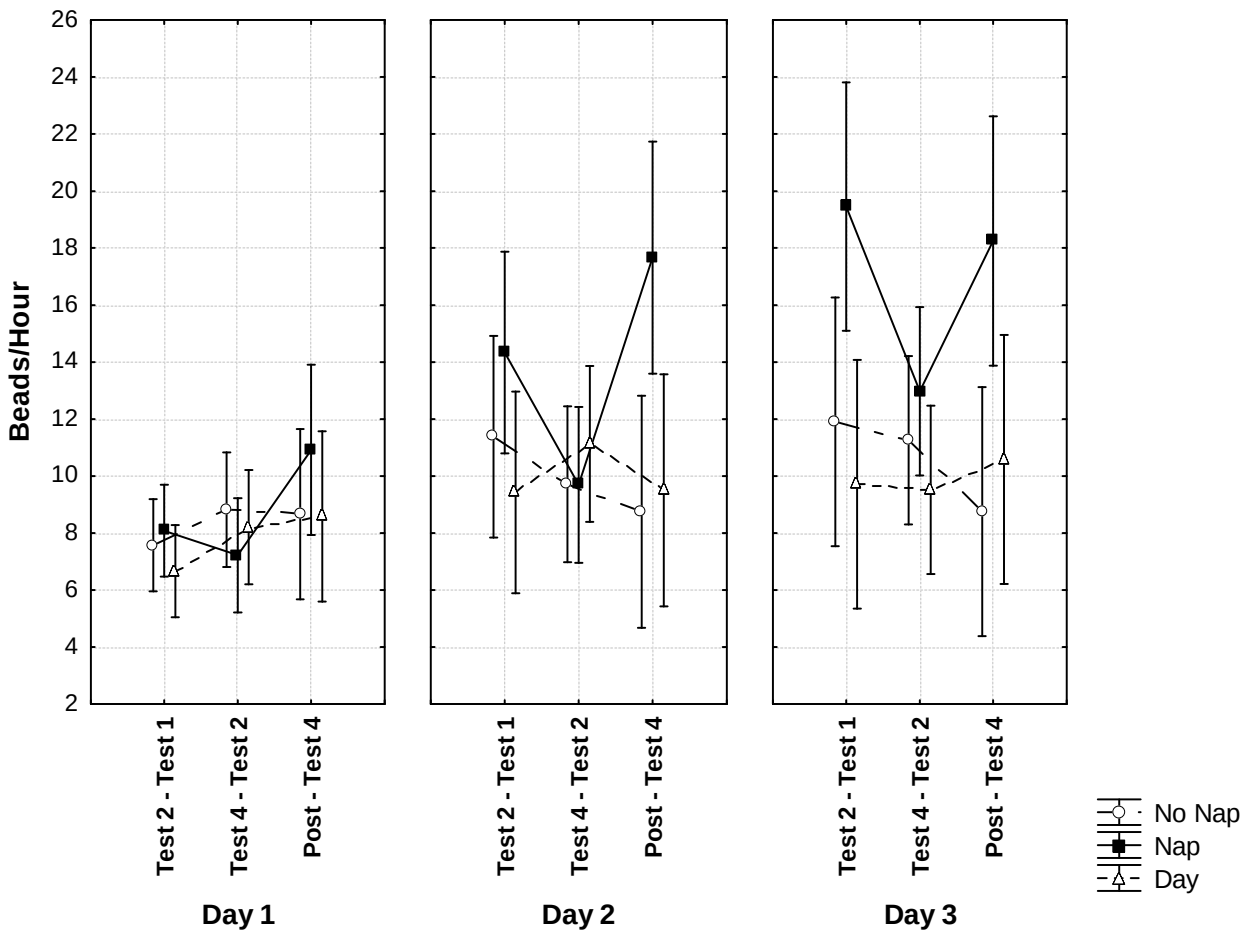

Figure 6: Beading performance for all three conditions over the three separate testing nights and days

PHYSIOLOGICAL MEASURES

Tympanic temperature

Analyses of the tympanic temperature recordings revealed the following. With reference to Figure 7and Table VII a significant *time effect* was found, indicating the marked effect of the circadian rhythm on tympanic temperature, which decreased consistently throughout the night: the lowest temperatures coincided with what was assumed to be the circadian nadir (±04h00 to 06h00). The nap group temperatures decreased (on average) by 0.35^{o}C from Test 1 to Test 4 over all three night shifts and the no nap group by 0.41^{o}C. Despite this, there was no interaction effect between *condition* and *time*. A significant *day effect* (p=0.048) demonstrated an

adaptation by the subjects to the unnatural working hours and resultant circadian disruptions. The interaction effect between *days* and *time* (p=0.018) refers to the impact that the adaptation experienced by the subjects over the three shifts had on the circadian rhythm temperature profile: tympanic temperature profiles for both groups started higher and ended higher on the third night shift, relative to the first two night shifts. No significant *condition effect*s or *final effects* were observed.

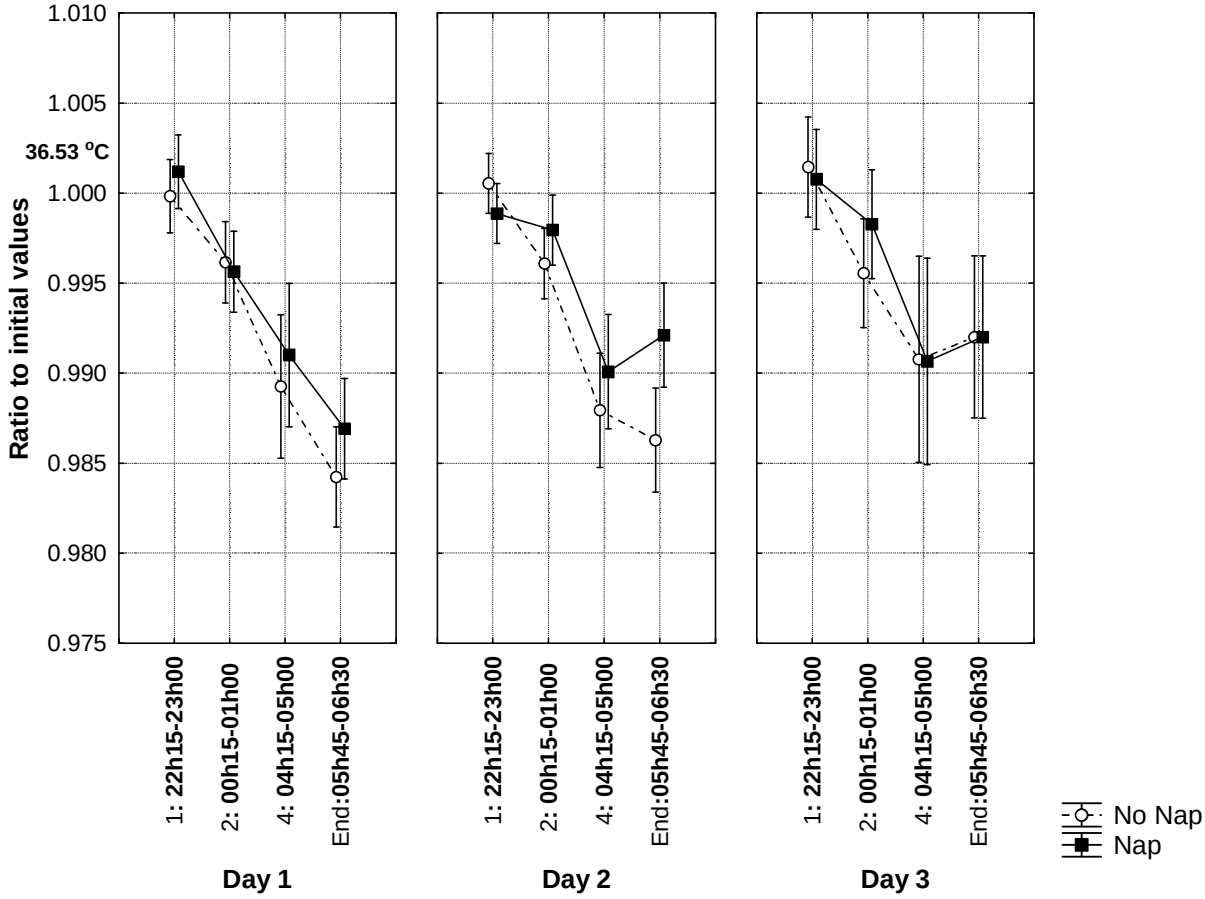

Figure 7**:** Tympanic temperature responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

A *roll-over effect* was found with regard to the tympanic temperature responses over the three shifts. Illustrated in Figure 8 and Table VII, napping evoked significantly lower (p=0.039) fluctuations in tympanic temperature responses when compared to the no napping condition, demonstrating a reduced *fatigue effect*. This was indicative

of the nap group adapting faster than the no nap group to the night shifts. As a result of this adaptation to the shift work and the reduced *fatigue effect*, the *recovery effect* was also significantly different between the two night conditions: the napping group's temperature changes were less pronounced, when compared to the no napping group (p=0.004).

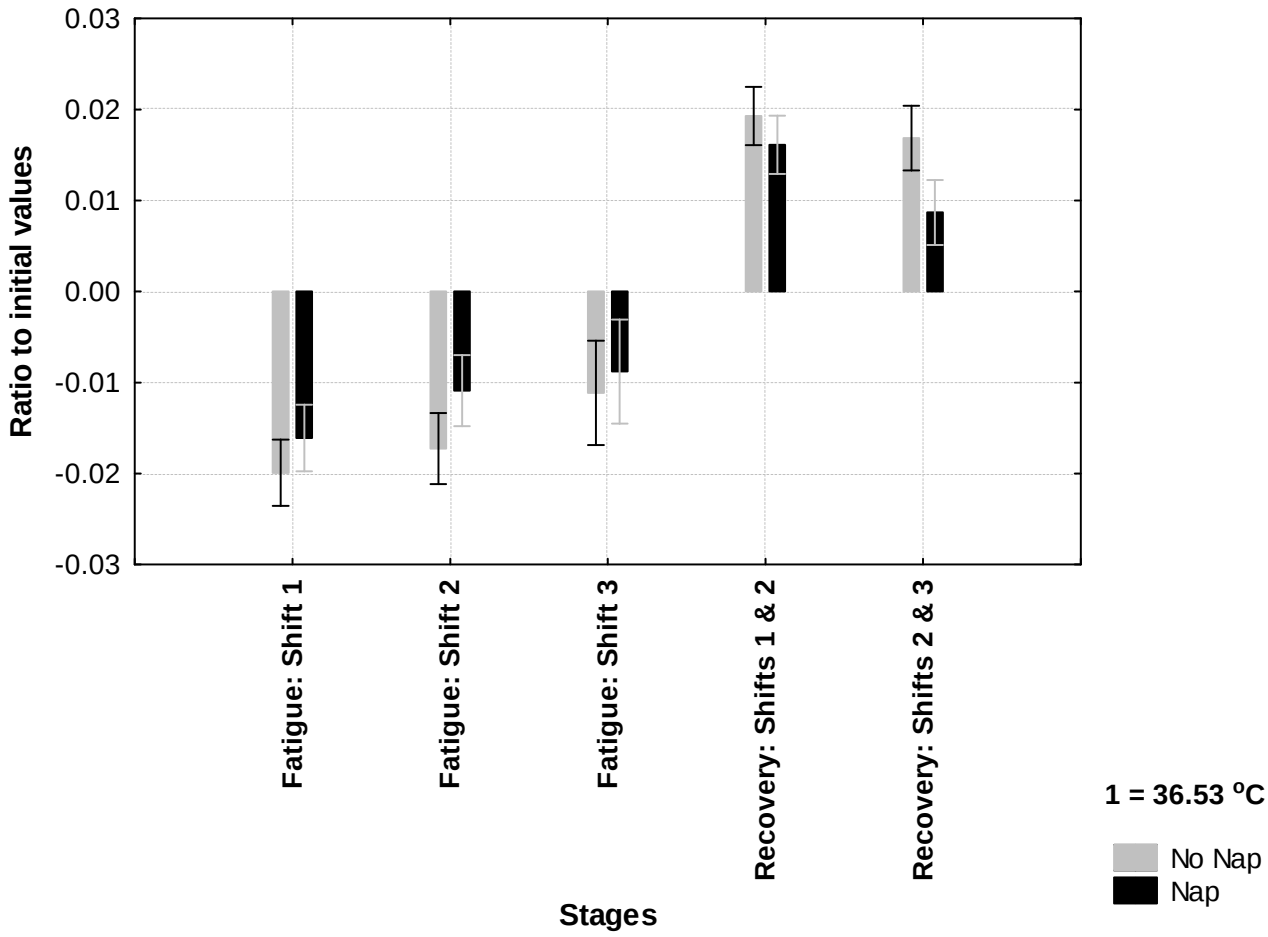

Figure 8**:** Fatigue and recovery effects for tympanic temperature responses during all three night shifts for both conditions. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values

Table VII**:** Statistical effects for tympanic temperature (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0	1,22	0	2	0.187
Days	0	2,44	0	3	0.048 *
Time	0.007	3,66	0.002	71	0.000 *
Days*Condition	0	2,44	0	0	0.665
Time*Condition	0	3,66	0	1	0.406
Days*Time	0	6, 132	0	3	0.018 *
Days*Time*Condition	0	6, 132	0	1	0.321
Condition*Chronotype	0	2,44	0	1	0.546
Final	0	1,22	0	0	0.977
Fatigue	0	1,22	0	4.817	0.039 *
Recovery	0	1,22	0	10.362	0.004 *

Skin temperature

In keeping with the trend of tympanic temperature, skin temperature recordings expressed a significant *time effect* each night, indicating the marked effect of the circadian rhythm (Figure 9 and Table VIII). Skin temperature measurements for both conditions decreased significantly during the night, with the lowest temperatures coinciding with the circadian nadir, as witnessed in tympanic temperature readings.

Table VIII**:** Statistical effects for skin temperature (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0	1,22	0	0.4	0.557
Days	0.005	2,44	0.003	17.4	0.000 *
Time	0.013	3,66	0.004	22	0.000 *
Days*Condition	0	2,44	0	1	0.37
Time*Condition	0	3,66	0	0.6	0.647
Days*Time	0.004	6, 132	0.001	4	0.001 *
Days*Time*Condition	0.001	6, 132	0	1	0.456
Condition*Chronotype	0.001	2,44	0	1.1	0.366
Final	0	1,22	0	1.59	0.221
Fatigue	0	1,22	0	0.147	0.705
Recovery	0	1,22	0	0.068	0.796

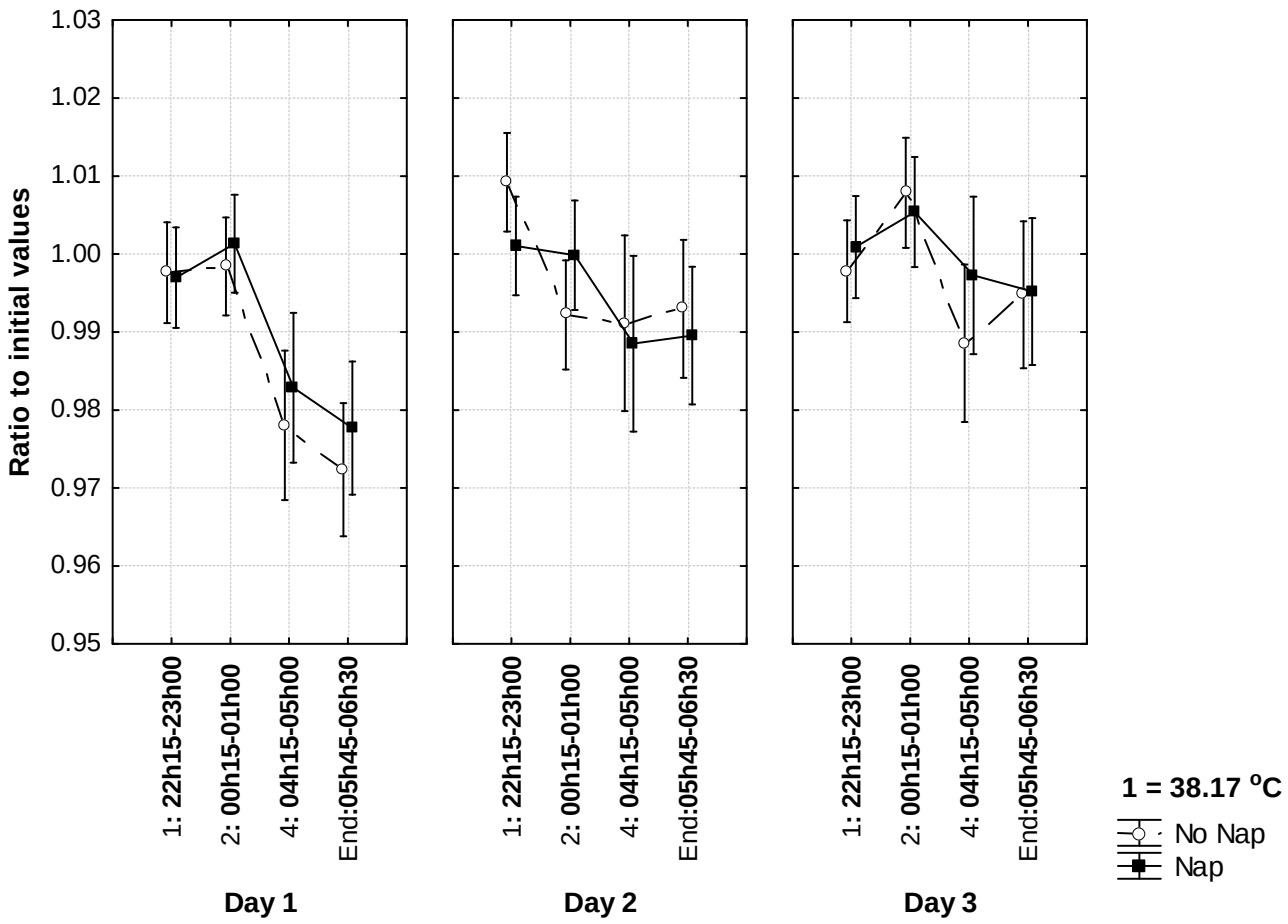

Figure 9**:** Skin temperature responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

A significant difference was also exhibited between the three night shifts (*day effect)*, indicating a possible adaptation by the subjects to working during the irregular night shift cycles. This could also be accounted for by the simultaneous increase in tympanic temperature profiles on the third night. Finally, the interaction effect between *days* and *time* illustrated that the subjects may have begun to adapt to the night shift, with this adaptation causing a change in circadian-modulated skin temperature responses. No *condition* or *final effects* were found.

No significant *condition effects* were found regarding *fatigue* and *recovery effects*, but as evinced in Figure 10, skin temperature responses changed considerably for both conditions over the three shifts. The extent of the temperature fluctuation decreased significantly over the three days, with the inter-shift responses for both conditions following the same trend. These changes demonstrate the adaptation of both groups to shift work, which may have resulted in concomitant changes in performance and response patterns. In this case, these results depict much the same trends as the *days* and *time* interaction effects

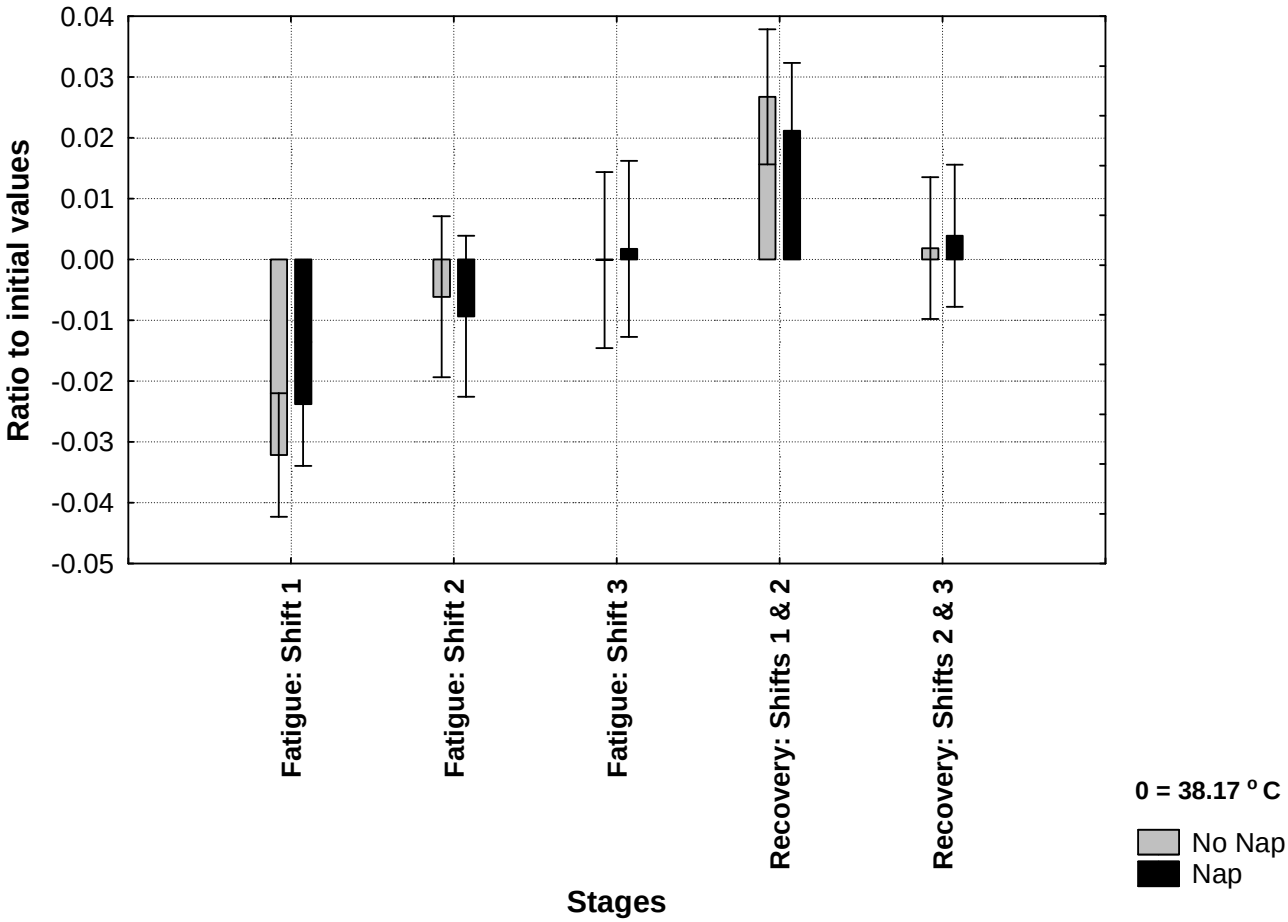

Figure 10**:** Fatigue and recovery effects for skin temperature responses during all three night shifts for both conditions. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Heart rate frequency

All data shown in this section refer to only the heart rate measures recorded during each subject's 15-minute test battery: all subjects performed the same tasks in the same order for the same amount of time. This was done in the attempt to observe the heart rate and autonomic changes associated with shift work and match these phenomena to the performance and response changes. The standardization and repetition would therefore limit the impact of any potential confounding effects induced by other mental or physical activities practised outside of the testing times.

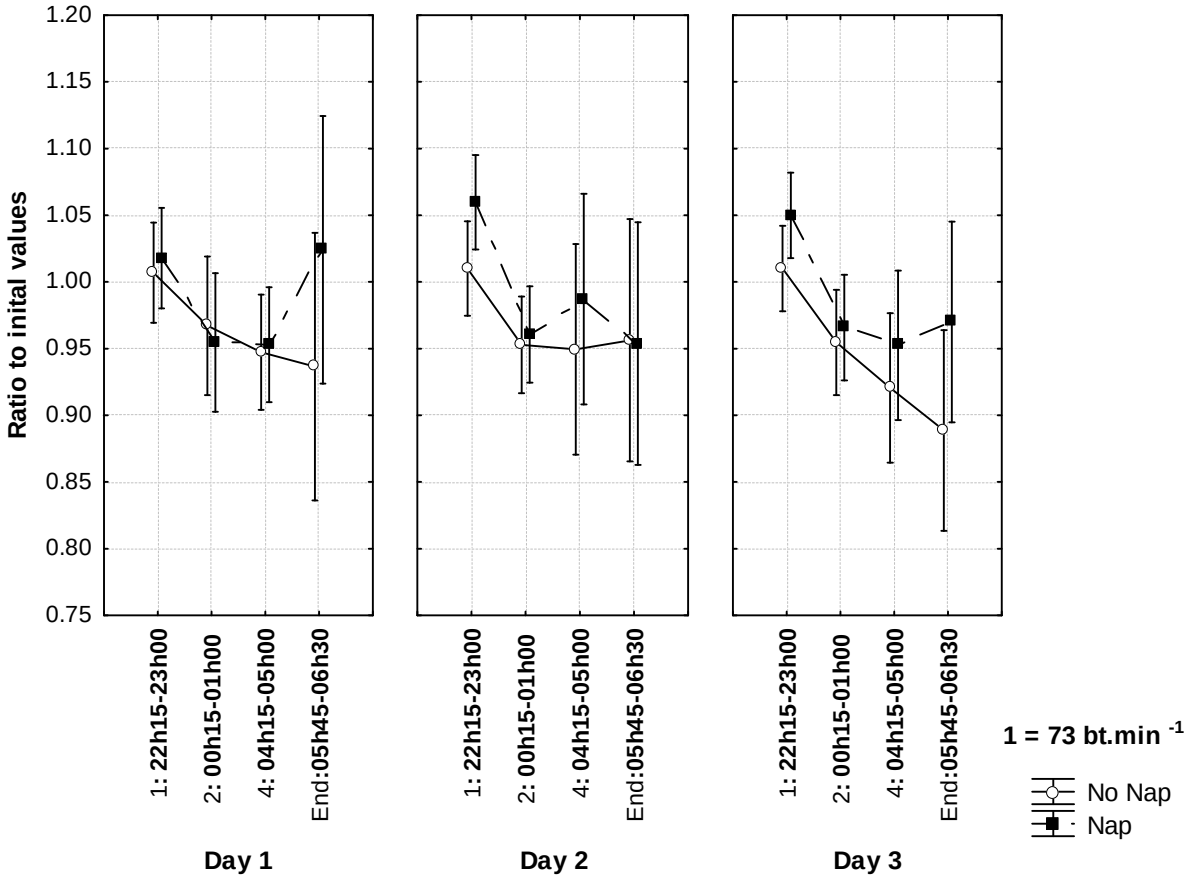

Figure 11: Heart rate frequency responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Table IX: Statistical effects for heart rate frequency (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.061	1,22	0.061	4.92	0.037 *
Days	0.012	2,44	0.006	0.39	0.682
Time	0.271	3,66	0.09	7.22	0.000 *
Days*Condition	0.005	2,44	0.003	0.17	0.843
Time*Condition	0.026	3,66	0.009	0.7	0.557
Days*Time	0.039	6, 132	0.006	0.87	0.515
Days*Time*Condition	0.036	6, 132	0.006	0.8	0.568
Condition*Chronotype	0.064	2, 44	0.032	2.941	0.079
Final	0.04	1,22	0.04	3.118	0.091
Fatigue	0.0205	1,22	0.021	0.643	0.431
Recovery	0.0186	1,22	0.019	0.498	0.488

A significant *condition effect* was found with regard to the heart rate responses over the three night shifts: overall, the nap group produced significantly higher heart rate responses relative to the no nap group. As illustrated in Figure 11, the heart rate responses for the nap group also increased after the nap, resulting in higher end-of-shift heart rates when compared to the no nap group. A significant *time effect* was found, demonstrating the effect of the circadian rhythm and the simultaneous reduction in body temperature on heart rate. Independent of condition, heart rate decreased significantly over the course of each night, with the lowest responses being recorded during the circadian nadir, between Test 4 (04h15 to 05h00) and the End-of-shift test (05h45 to 06h30). No additional effects were observed.

Further analysis revealed that there were no significant *general* differences between the heart rate frequency responses recorded for the nap condition when compared to both the no nap and day conditions (Appendix C, Table 2).

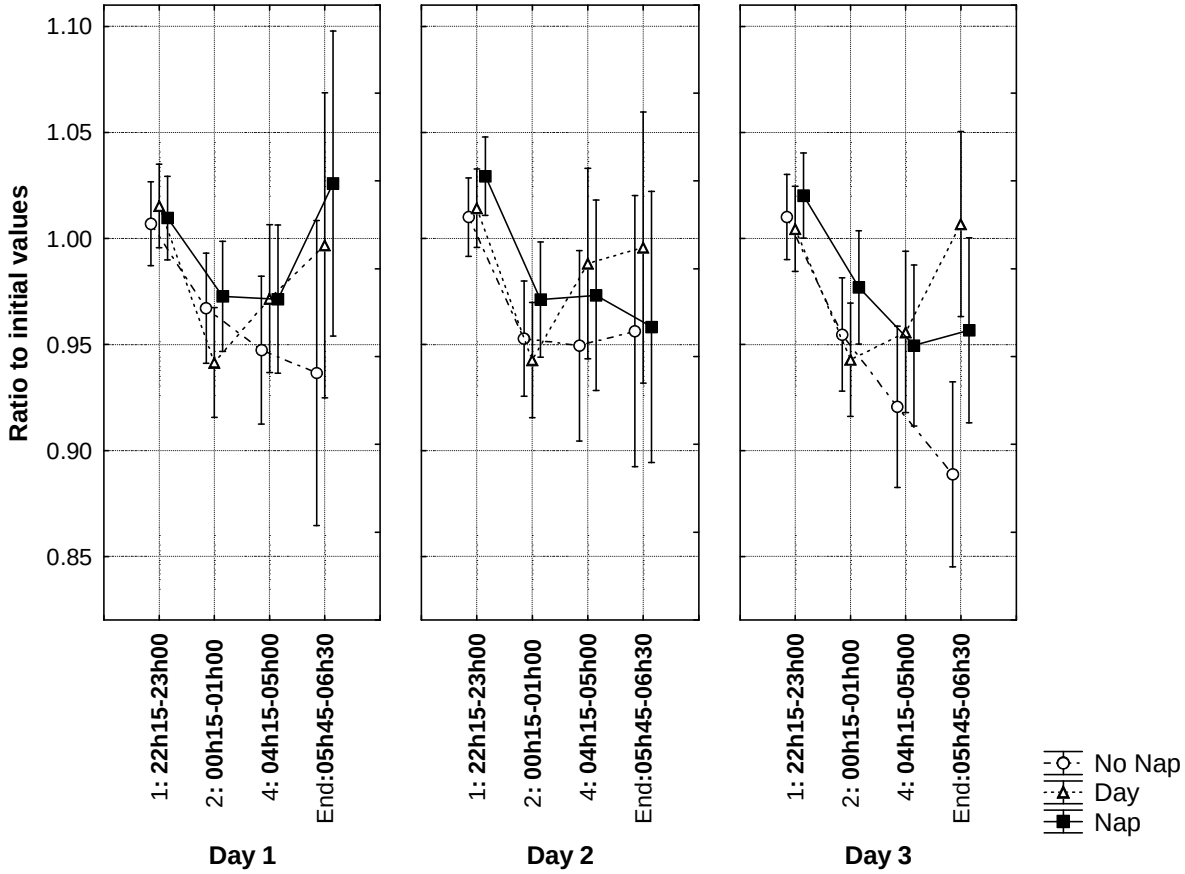

Figure 12: Heart rate frequency responses for all three conditions over the three separate testing nights and days. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Heart rate variability

With reference to Figure 13, heart rate variability responses (RR intervals) did not differ significantly between the two conditions over the three days of testing. However, there was a significant *time effect*: heart rate variability responses demonstrated a circadian effect, decreasing over the course of the night, with the lowest levels occurring at much the same time as the heart rate frequency minimum. In cognisance of the fact that the intervals during which these measurements were taken were the test batteries, the reduction in heart rate variability may be indicative of increased levels of mental activity associated with the variables assessed during the test period. No other effects were found.

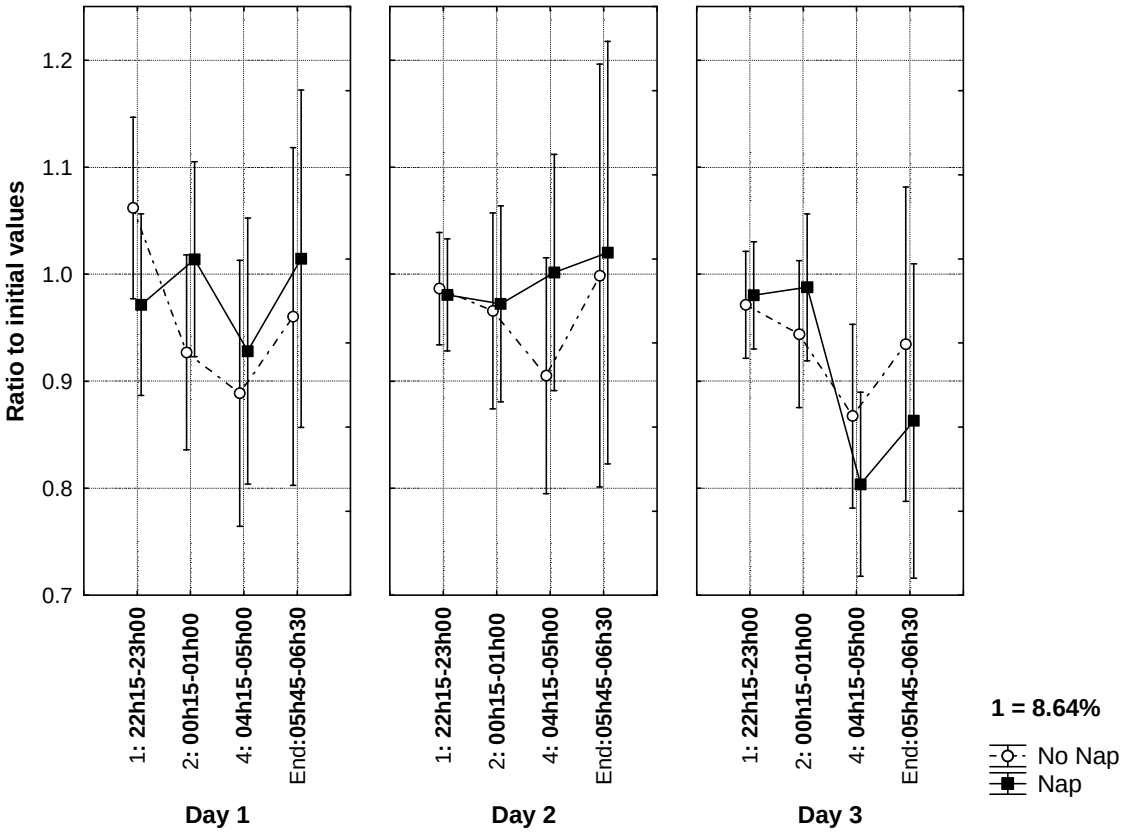

Figure 13: Heart rate variability responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Table X: Statistical effects for heart rate variability (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.008	1,22	0.008	0.128	0.724
Days	0.202	2,44	0.101	2.661	0.081
Time	0.344	3,66	0.115	3.228	0.028 *
Days*Condition	0.036	2,44	0.018	0.468	0.629
Time*Condition	0.056	3,66	0.019	0.522	0.669
Days*Time	0.155	6, 132	0.026	0.832	0.547
Days*Time*Condition	0.149	6, 132	0.025	0.8	0.572
Condition*Chronotype	0.215	2, 44	0.107	2.097	0.152
Final	0.01	1,22	0.01	0.33	0.572
Fatigue	0.012	1,22	0.012	0.106	0.748
Recovery	0.063	1,22	0.063	0.478	0.496

High frequency power (HF)

No significant *condition effects* were found for the HF component of heart rate variability over the three days (Figure 14 and Table XI). However, the nap group generally displayed elevated parasympathetic activity, evidenced by higher HF values.

Table XI: Statistical effects for high frequency power (high frequency) (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.302	1,22	0.302	0.954	0.339
Days	1.674	2,44	0.837	4.744	0.014 *
Time	2.003	3,66	0.668	3.922	0.012 *
Days*Condition	0.369	2,44	0.184	1.045	0.369
Time*Condition	0.343	3,66	0.114	0.673	0.572
Days*Time	1.631	6, 132	0.272	2.424	0.030 *
Days*Time*Condition	0.745	6, 132	0.124	1.106	0.362
Condition*Chronotype	0.21	2, 44	0.105	0.369	0.697
Final	0.024	1,22	0.024	0.172	0.683
Fatigue	0.215	1,22	0.215	0.369	0.550
Recovery	0.819	1,22	0.819	1.608	0.218

A significant *day effect* was observed which demonstrated how HF was significantly higher during the second night shift when compared to the first shift. It then decreased significantly during the third shift: this may have been indicative of an adaptation effect. A significant *time effect* was also found: HF tended to decrease over the initial tests of the shift, which was indicative of the sympathetic nervous system exerting a more prominent effect on cardiac regulation. This was supported by the simultaneous drop in heart rate variability during the third night shift. However, during all three nights, HF increased after Test 4 (04h15 to 05h30), displaying an effect of the parasympathetic nervous system. Finally, a significant *day* and *time* interaction demonstrated the effect of the irregular night work on the parasympathetic responses over the three night shifts: the unnatural hours of wakefulness resulted in a diminished parasympathetic response over the course of

three days, which indicates an unnatural modulation of cardiac responses. No additional effects were deduced.

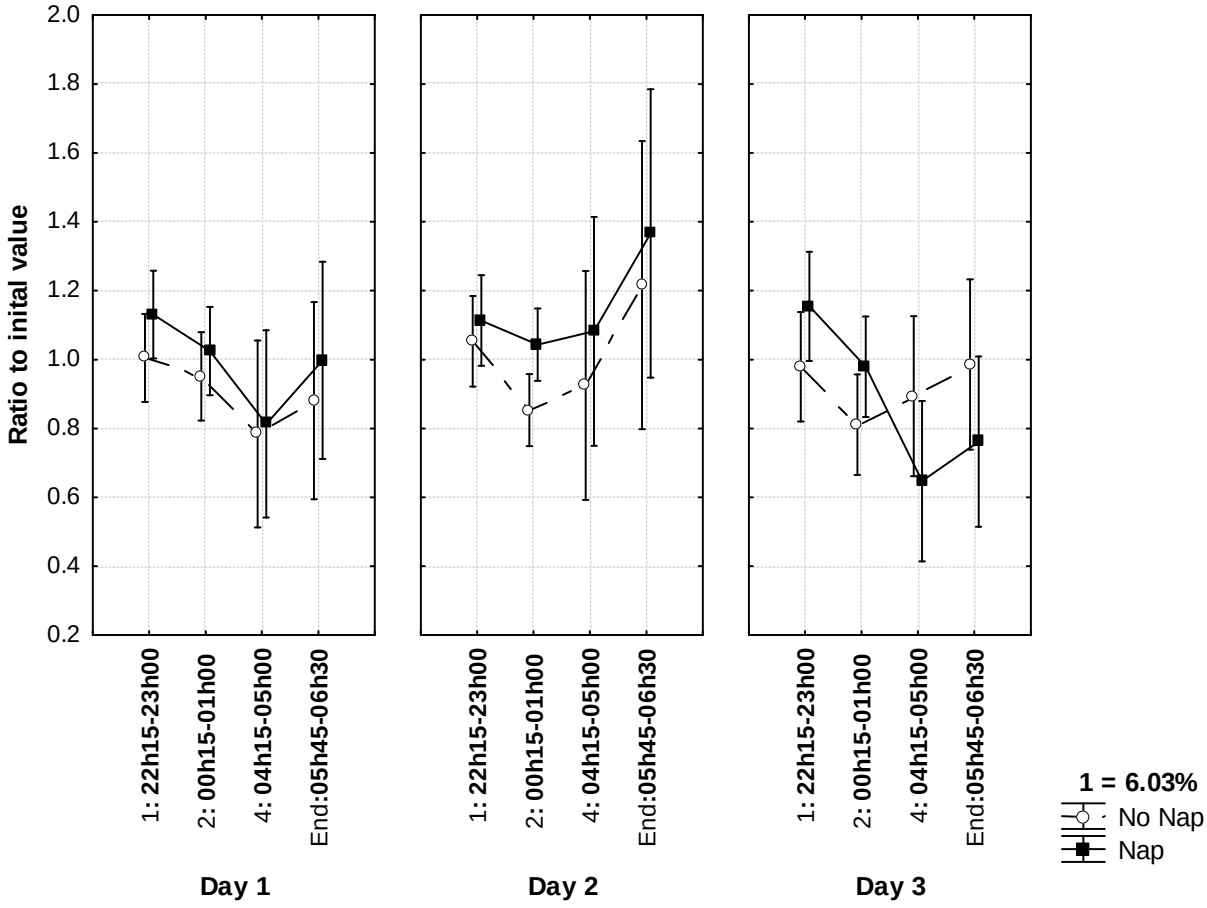

Figure 14: High frequency power responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Low frequency power (LF)

Regarding the low frequency power component (LF), napping when compared to no napping, did not elicit any significant differences over the course of the three nights of testing (Table XII). In an attempt to cope with the unnatural hours of wakefulness, however, a significant *day effect* was established, which was indicative of an adaptation by the subjects to the night work. Referring to Figure 15, LF and therefore

sympathetic modulation were significantly higher during the second shift than during either of the other two shifts.

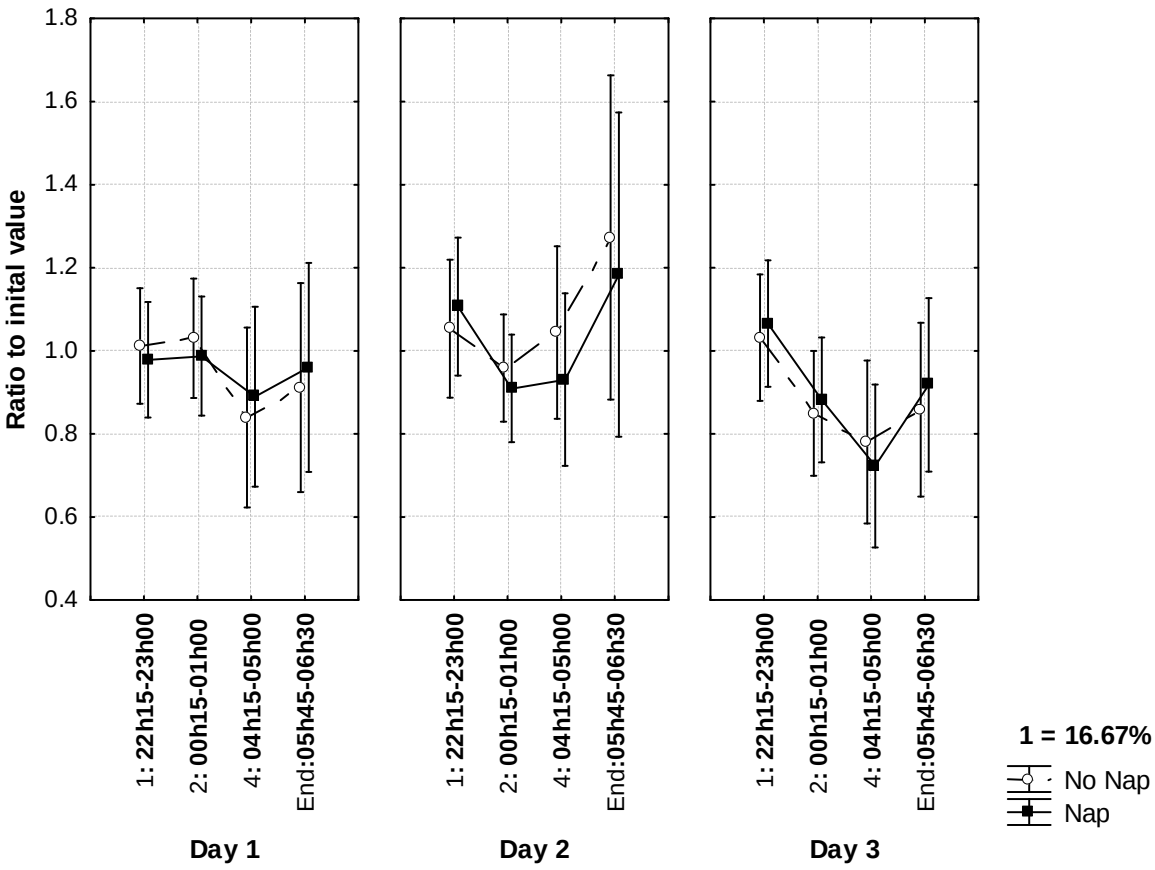

Figure 15: Low frequency power responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

As was the case in the HF analyses, a significant difference was found between the measures of LF over the course of the night (*time effect)*: during all shifts, sympathetic activity decreased consistently towards the latter half of the night and early morning. However during each shift, an increase in LF occurred after Test 4 (04h15 to 05h00), indicating an increased sympathetic effect. This may potentially have been indicative of a circadian upswing or conversely the effect of increased mental activity and concentration in the attempt to counteract the reduction in alertness during the circadian nadir.

Table XII: Statistical effects for heart rate variability (low frequency) (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.006	1,22	0.006	0.032	0.859
Days	1.398	2,44	0.699	5.297	0.009 *
Time	1.355	3,66	0.452	3.890	0.013 *
Days*Condition	0.061	2,44	0.031	0.231	0.795
Time*Condition	0.037	3,66	0.012	0.107	0.956
Days*Time	1.227	6, 132	0.205	1.884	0.088
Days*Time*Condition	0.155	6, 132	0.026	0.238	0.963
Condition*Chronotype	0.255	2, 44	0.128	0.718	0.501
Final	0.007	1,22	0.007	0.060	0.809
Fatigue	0.064	1,22	0.064	0.124	0.728
Recovery	0.059	1,22	0.059	0.104	0.751

Low/high frequency band ratio (LF/HF)

Referring to Table XIII, no general *condition effects* were found in the LF/HF analyses either. A significant *time effect* was observed over the three days, during which the LF/HF tended to increase throughout the each night shift, indicating a greater sympathetic modulation of cardiac activity (Figure 16 and Table XIII). Owing to the fact that the intervals were set up during the 15-minute testing batteries, this increase in sympathetic activity could be explained by the subjects increasing their concentration during the testing, in an attempt to overcome the circadian-related drowsiness associated with being awake at that time of the day. No additional effects were observed.

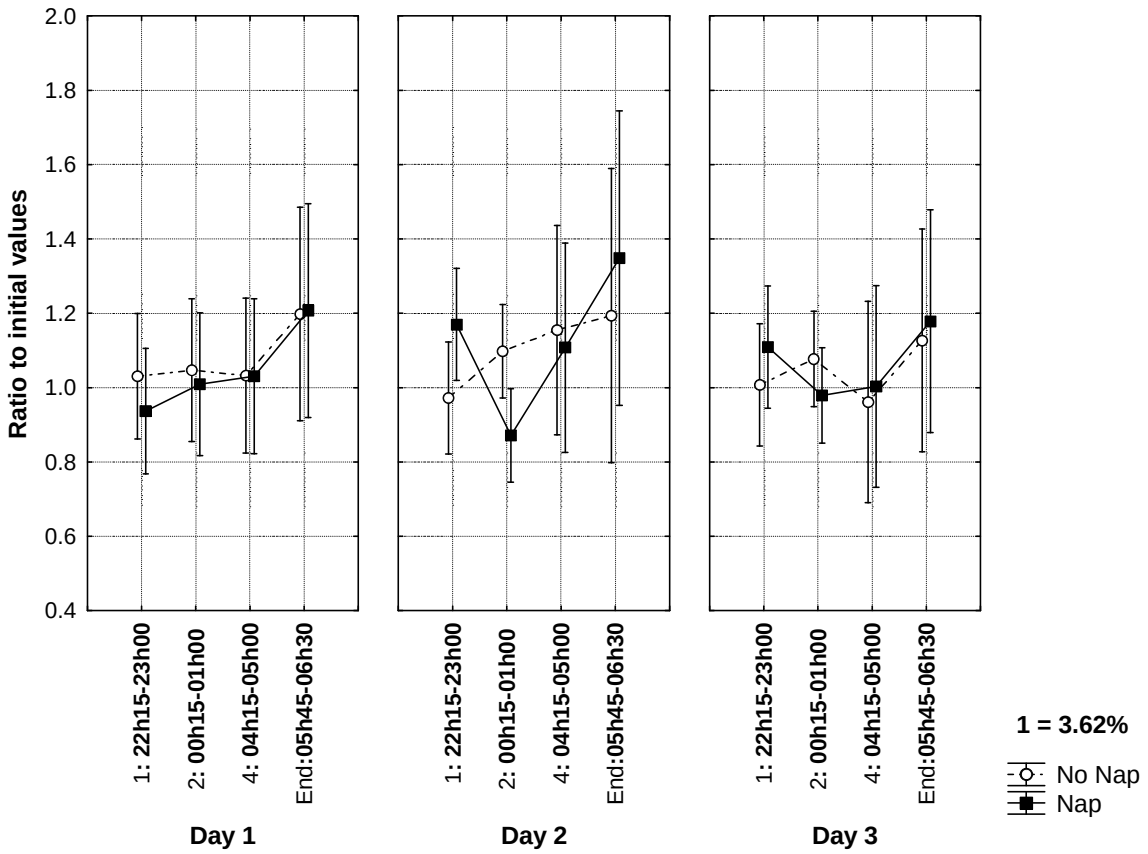

Figure 16: High/Low frequency band ratios for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Table XIII: Statistical effects for High/Low frequency band ratio (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.001	1,22	0.001	0.004	0.953
Days	0.203	2,44	0.102	0.693	0.505
Time	1.713	3,66	0.571	3.232	0.028 *
Days*Condition	0.045	2,44	0.023	0.155	0.857
Time*Condition	0.439	3,66	0.146	0.828	0.483
Days*Time	0.380	6, 132	0.063	0.557	0.763
Days*Time*Condition	0.423	6, 132	0.071	0.620	0.714
Condition*Chronotype	0.101	2, 44	0.051	0.123	0.885
Final	0.014	1,22	0.014	0.054	0.819
Fatigue		1,22			
Recovery		1,22			

PERFORMANCE INDICATORS

Simple reaction time

Simple reaction time was assessed through a simple computer-based task in which subjects had to react to the presentation of a yellow circle that appeared at intervals of between 1000 and 2000 ms, by clicking a computer mouse. Overall, napping responses did not differ significantly from the no nap condition over the three shifts (Table XIV). The nap group's responses were poorer on the first night, but improved thereafter (Figure 17). As with the high and low precision response times, natural circadian changes induced a significant *time effect,* with slower reaction times being recorded during the latter half of the night shifts.

Table XIV**:** Statistical effects for simple reaction time responses

	SS	Degrees of Freedom	MS	F	p
Condition	0.023	1,22	0.023	0.8	0.382
Days	0.006	2,44	0.003	0.12	0.886
Time	0.37	3,66	0.124	5.94	0.001 *
Days*Condition	0.154	2,44	0.077	3.38	0.043 *
Time*Condition	0.029	3,66	0.01	0.46	0.709
Days*Time	0.052	6, 132	0.009	0.43	0.858
Days*Time*Condition	0.316	6, 132	0.053	2.59	0.021 *
Condition*Chronotype	0.196	2,44	0.098	4.412	0.028 *
Final	0.106	1,22	0.106	3.02	0.021 *
Fatigue	0.079	1,22	0.079	2.616	0.125
Recovery	0	1,22	0	0.002	0.965

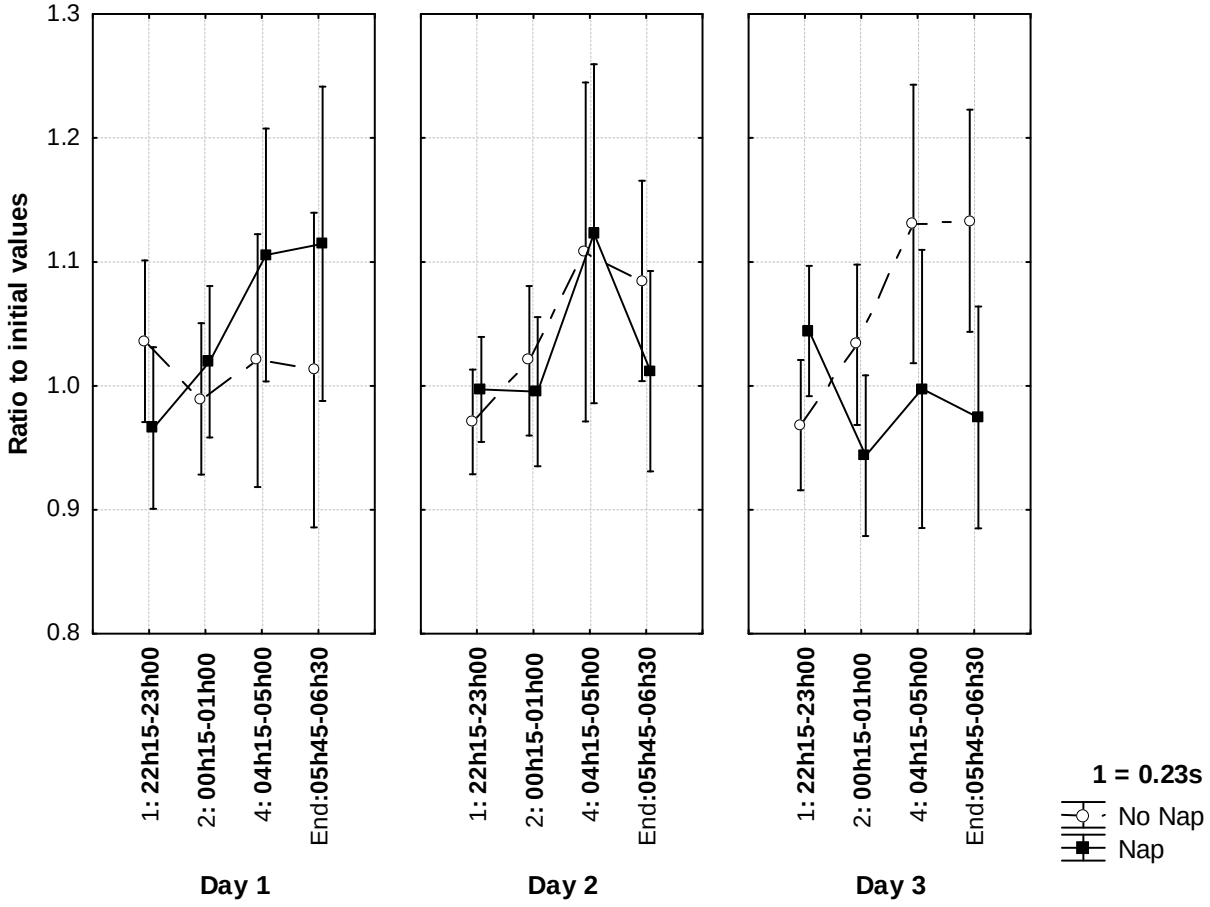

Figure 17**:** Simple reaction time responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Furthermore, a three-way interaction effect was observed between *condition, days* and *time*. In essence, the nap condition had a positive effect on the circadian-related changes in reaction time over the three night shifts, reducing the severity of these natural fluctuations in the subject's responses, which are known to be negatively affected by circadian oscillations. This in turn resulted in a reduction in simple reaction time by the third day (*final effect)*, when compared to no nap condition.

A further significant *day* and *condition* interaction effect illustrated the impact that the condition had on the habituation of the subjects over the three night shifts: as evidenced in Figure 17, napping aided in reducing reaction time over the course of the three nights when compared to the no nap condition.

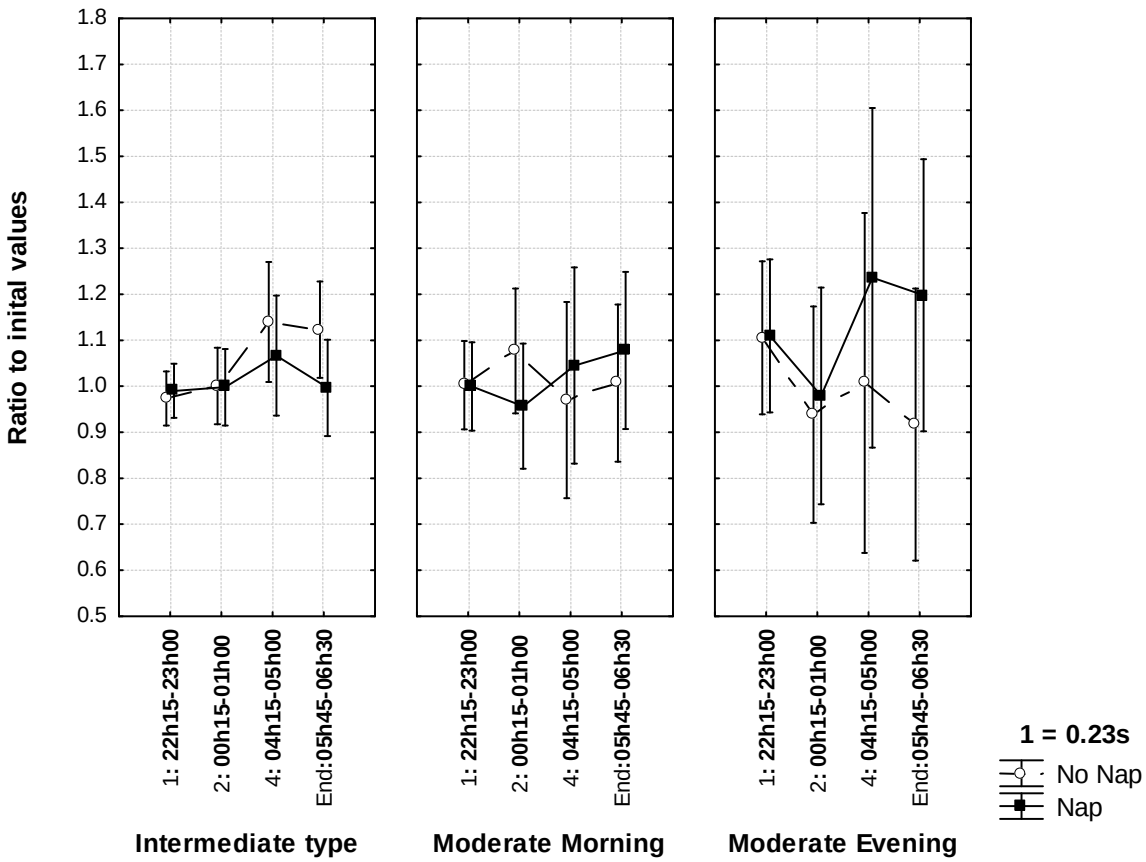

Figure 18**:** Average reaction time responses for both conditions and the effect of chronotype. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

A *chronotype* and *condition effect* was observed, demonstrating that the effect of the condition (nap compared to no nap) is dependent on the chronotype of the individual. Shown in Figure 18, the nap inclusion tended to be more appropriate for intermediate and moderate morning types, as these two chronotypes' responses tended to stabilise over the course of the night shifts. With regard to the moderate evening types, the inclusion of the nap resulted in a significant increase in reaction time, when compared to the no nap condition. The reaction times observed for the moderate evening types during the no nap group generally improved over the course of the night shifts.

High precision response time (modified Fitt's tapping task)

This measure involved exposing all subjects to a high precision test (index of difficulty = 5.66), in which 25 yellow dots randomly appeared on a touch screen with an inter-cycle delay of between 500 and 1000ms. Subjects were required to react to the dots as quickly and as accurately as possible.

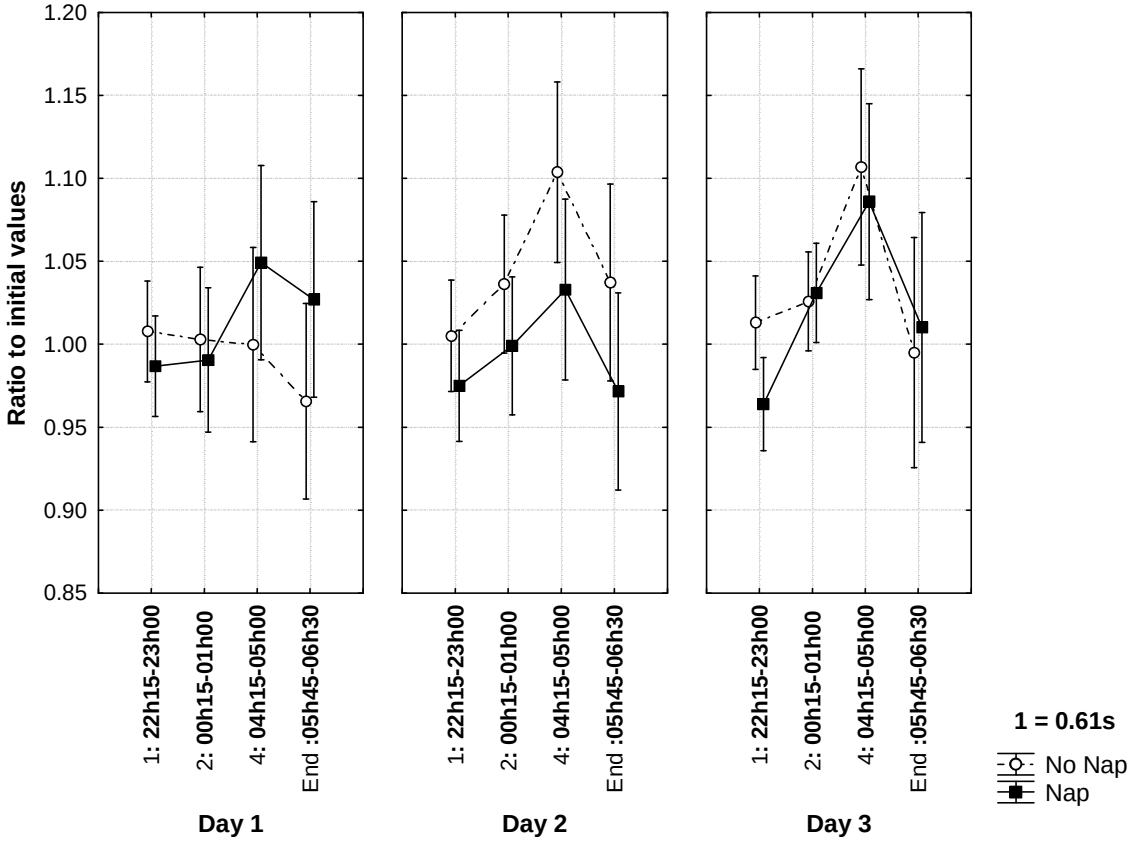

Figure 19**:** High precision Fitts' tapping task response times for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

With reference to the *general effects,* napping, when compared to the no napping condition, did not elicit significantly faster response times over the three night shifts. During shift 1 however, the nap group's response time did slow down drastically between Test 2 (00h15 to 01h00) and Test 4 (04h15 to 05h00) when compared to the no nap group, potentially as a result of residual sleep inertia following the nap. There was however an overall significant *time effect* during each shift: for both

conditions, response time slowed down over the course of the night, demonstrating the effect of the natural circadian changes and sleep pressure build up on these responses. There was also a significant interaction effect between *days* and *condition* (p=0.040, Table XV), which explains how the two difference conditions had opposing effects on the habituation of the subjects over the three night shift cycle: as illustrated in Figure 19, napping resulted in varied response times over the course of three shifts, with the responses during shift 1 being significantly different to the responses during the subsequent shifts. No *final effects* for response times were observed. Furthermore, Figure 19 illustrates the effect of the circadian "upswing", in that the End-of-shift test (05h45 to 06h30) response times tended to be faster than test 4 (04h15 to 05h00) response times, particularly on Days 2 and 3. *Chronotype* did not elicit an effect either and no *roll-over effects* were found.

Table XV**:** Statistical effects for high precision response times (* denotes a significant effect).

	SS	**Degrees of Freedom**	**MS**	**F**	**p**
Condition	0.016	1,22	0.016	1.47	0.238
Days	0.032	2,44	0.016	1.84	0.171
Time	0.217	3,66	0.072	11.84	0.000 *
Days*Condition	0.059	2,44	0.03	3.47	0.040 *
Time*Condition	0.012	3,66	0.004	0.67	0.571
Days*Time	0.046	6, 132	0.008	1.31	0.257
Days*Time*Condition	0.042	6, 132	0.007	1.19	0.315
Condition*Chronotype	0.006	2,44	0.003	0.26	0.774
Final	0.003	1,22	0.003	0.27	0.608
Fatigue	0.025	1,22	0.025	1.238	0.278
Recovery	0.031	1,22	0.031	1.87	0.185

Low precision response time (modified Fitts' tapping task)

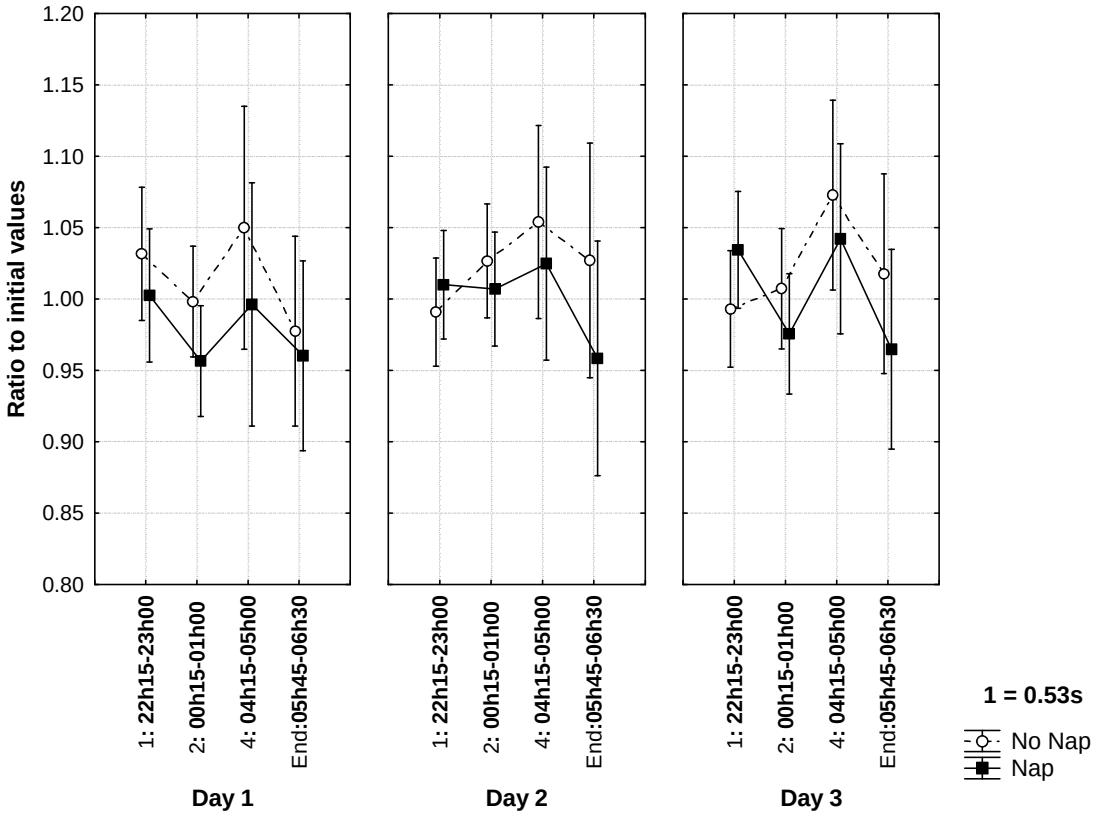

Figure 20: Low precision Fitts' tapping task response times for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

As with the high precision response task, the low precision task followed the exact same procedures, the only difference being that the index of difficulty was set at 3.44, rather than 5.66. As illustrated in Figure 20 and Table XVI, there was a significant effect observed with regard to *condition* (p=0.046): napping elicited faster response times (3 day mean for all tests: 0.511s ±0.017) consistently throughout all the night shifts, when compared to the no nap condition (3 day mean for all tests; 0.54 ±0.016). Additionally, the circadian rhythm fluctuations evoked a consistent and significant *time effect* over the course of each night, with response times being markedly slower during the latter half of the night. There were also no *chronotype* or *final effects* observed.

Table XVI**:** Statistical effects for low precision response time (* denotes a significant effect).

	SS	Degrees of Freedom	MS	F	p
Condition	0.049	1,22	0.049	4.46	0.046 *
Days	0.017	2,44	0.009	0.59	0.557
Time	0.126	3,66	0.042	4.2	0.009 *
Days*Condition	0.004	2,44	0.002	0.12	0.884
Time*Condition	0.034	3,66	0.011	1.14	0.34
Days*Time	0.029	6, 132	0.005	0.59	0.735
Days*Time*Condition	0.024	6, 132	0.004	0.5	0.809
Condition*Chronotype	0.012	2,44	0.006	0.45	0.643
Final	0.006	1,22	0.006	0.455	0.507
Fatigue	0.101	1,22	0.101	4.479	0.046 *
Recovery	0.026	1,22	0.026	1.287	0.269

A significant fatigue effect was found between the conditions for low precision response time (Table XVI and Figure 21). Napping, when compared to the no nap condition, resulted in significantly faster response times at the end of all three shifts, demonstrating a reduced *fatigue effect* over the course of all of the shifts (p=0.046). Despite the fact that responses were noticeably faster during shift 1 when compared to the latter two shifts, the nap aided in stabilising the extent of the response time variability during this time. Regarding the no nap group, response times were significantly slower at the end of the shift compared to those of the nap group, which resulted in a greater degree of fatigue experienced during the shifts. No significant *recovery effects* were noted. In spite of this, the fact that the response times for the napping condition remained consistent over the three shifts suggests that the inclusion of the nap had an effect on the responses, when compared to the no nap condition.

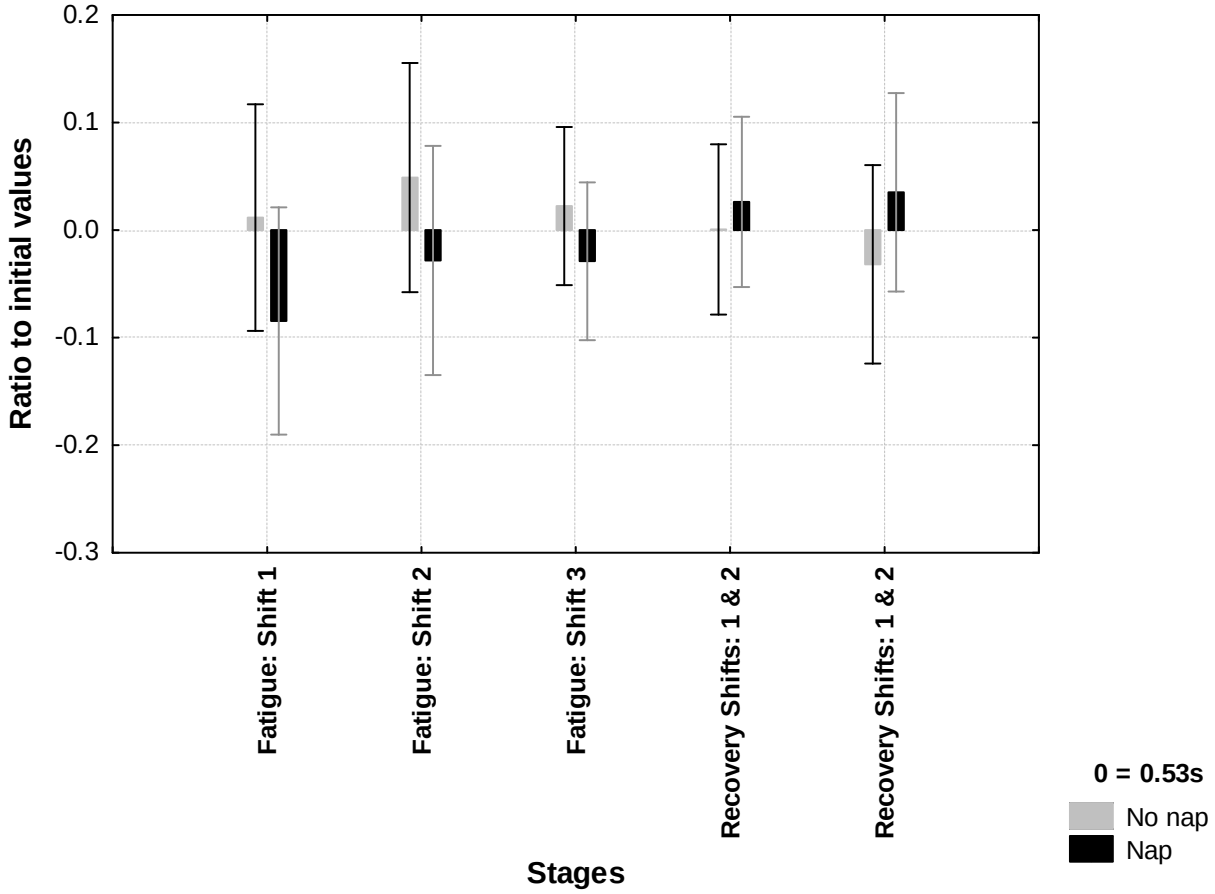

Figure 21**:** Fatigue and recovery (roll-over) effects for low precision response times during all three night shifts for both conditions. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

As napping elicited an effect on low precision response time during the night shifts, a further comparison was made with the responses observed during the day condition to determine the extent of this nap effect. As illustrated in Figure 22, the napping and no nap conditions followed much the same trends throughout the night, with napping consistently producing faster response times. The day condition followed a natural circadian effect: response time decreased over the day with the fastest responses occurring at the end of the shift. This coincided with the acrophase of the circadian rhythm. More detailed analysis revealed that no significant condition effects were observed between the day and nap conditions (p=0.31) but a significant difference between the day and the no nap group did exist (p=0.006). (Appendix C, Table 4).

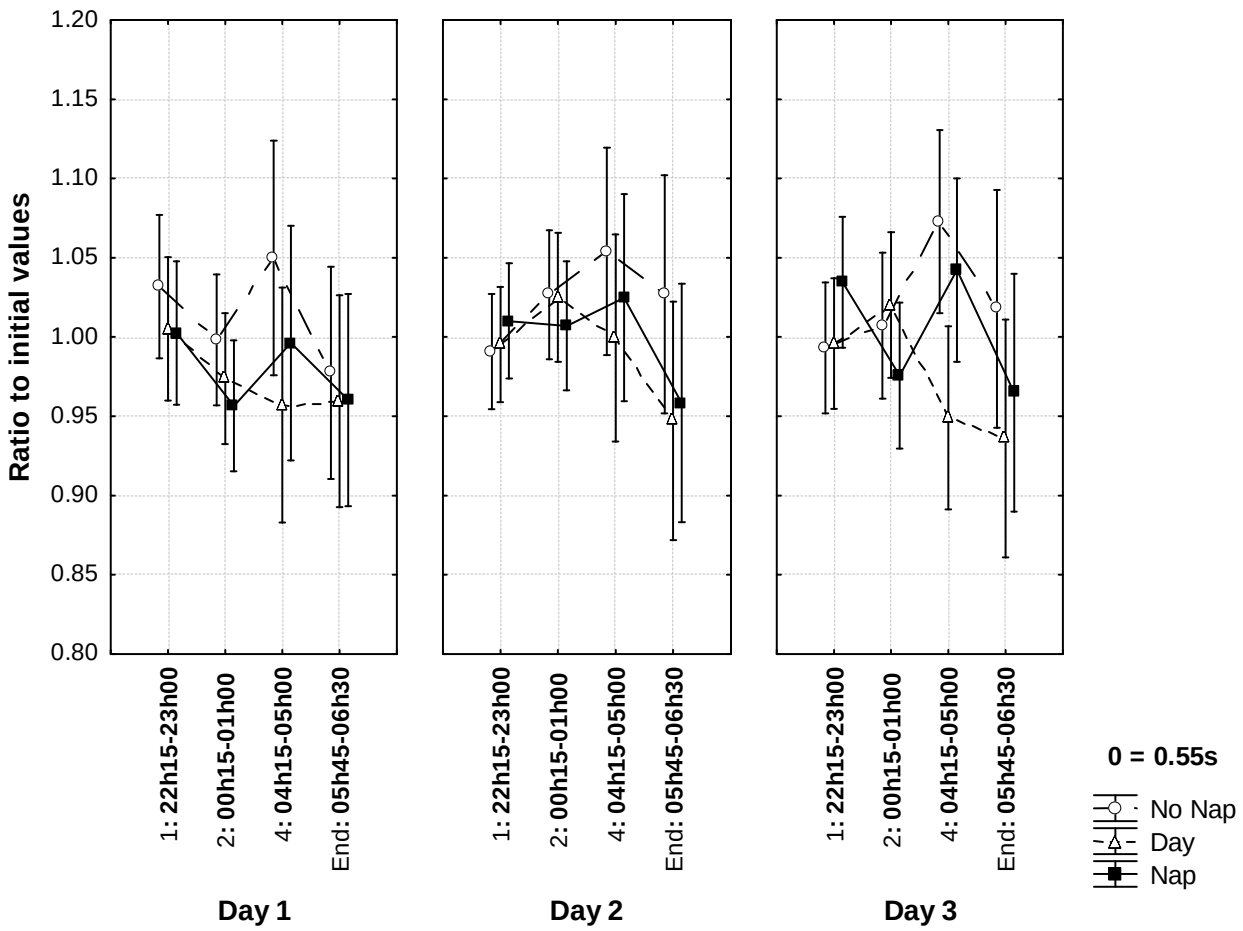

Figure 22**:** Low precision Fitts' tapping task response times for all conditions over the three separate testing nights and days. Note the testing times for the day shift were as follows: **1** = 08H15 to 09h00, **2** = 10h15 to 11h00, **4** = 14h15 to 15h00, **End of shift** = 15h45 to 16h30). All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values

High and low precision target deviation (Modified Fitts' tapping task)

No *general effects* were observed in either of the two target deviation tasks (Table XVII and Table XVIII. Napping had no impact on target deviation performance at the end of the last night shift (no *final effect*) and more generally over the course of the three night shifts, when compared to no napping. Similarly, there were no significant *day effects* on accuracy responses over the three night shifts for both conditions. The circadian rhythm did not have an effect on both variables either. Target deviation responses were also not affected by *chronotype* and no general *rollover effects* were noted for both high and low precision target deviations either.

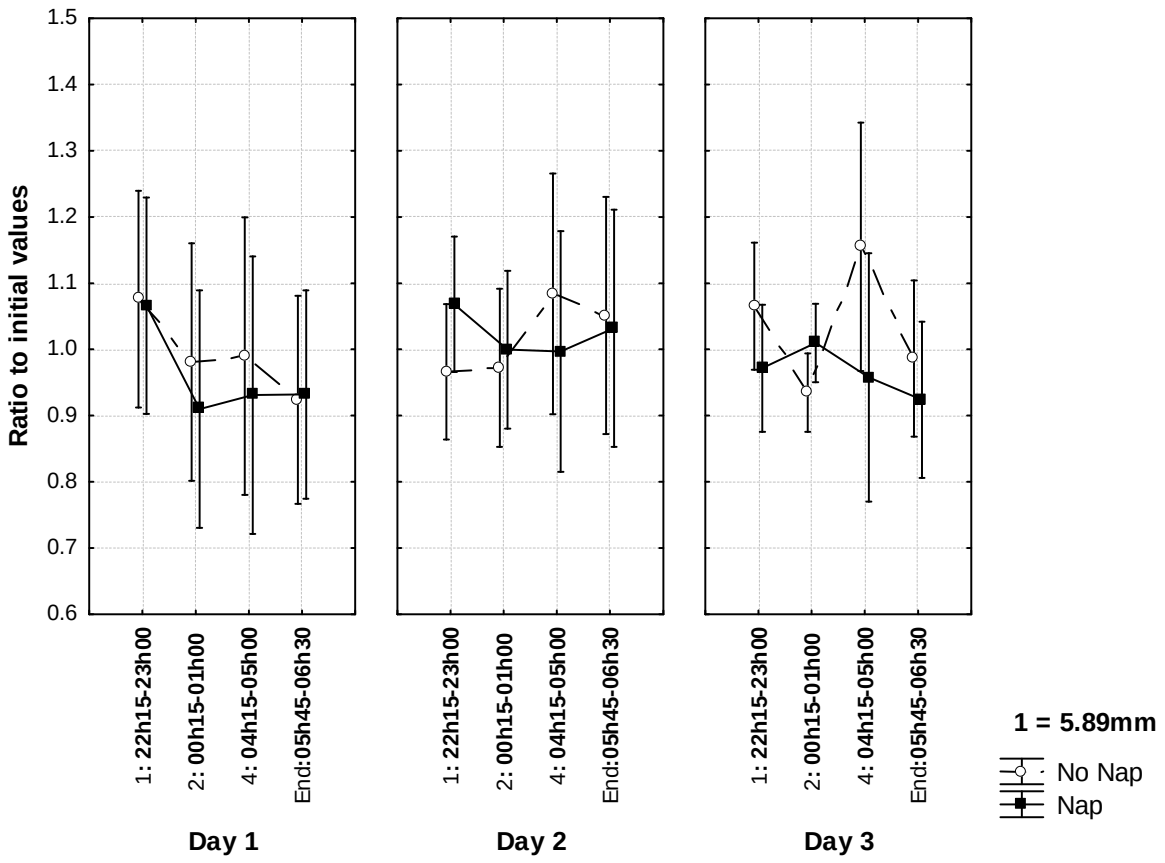

Figure 23**:** High precision target deviation responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Table XVII**:** Statistical effects for high precision target deviation responses

	SS	Degrees of Freedom	MS	F	p
Condition	0.075	1,22	0.075	1.012	0.325
Days	0.098	2,44	0.049	0.614	0.546
Time	0.236	3,66	0.079	1.24	0.302
Days*Condition	0.068	2,44	0.034	0.427	0.655
Time*Condition	0.174	3,66	0.058	0.913	0.439
Days*Time	0.264	6, 132	0.044	0.743	0.616
Days*Time*Condition	0.193	6, 132	0.032	0.544	0.774
Condition*Chronotype	0.141	2,44	0.07	0.851	0.443
Final	0.234	1,22	0.234	2.387	0.137
Fatigue	0.003	1,22	0.003	0.018	0.894
Recovery	0.033	1,22	0.033	0.217	0.646

Table XVIII**:** Statistical effects for low precision target deviation responses

	SS	Degrees of Freedom	MS	F	p
Condition	0.029	1,22	0.029	0.606	0.444
Days	0.127	2,44	0.064	1.571	0.219
Time	0.023	3,66	0.008	0.12	0.948
Days*Condition	0.038	2,44	0.019	0.471	0.627
Time*Condition	0.028	3,66	0.009	0.147	0.931
Days*Time	0.201	6, 132	0.034	0.762	0.601
Days*Time*Condition	0.096	6, 132	0.016	0.365	0.901
Condition*Chronotype	0.144	2,44	0.072	1.682	0.214
Final	0.003	1,22	0.003	0.04	0.843
Fatigue	0.005	1,22	0.005	0.058	0.811
Recovery	0.001	1,22	0.001	0.021	0.887

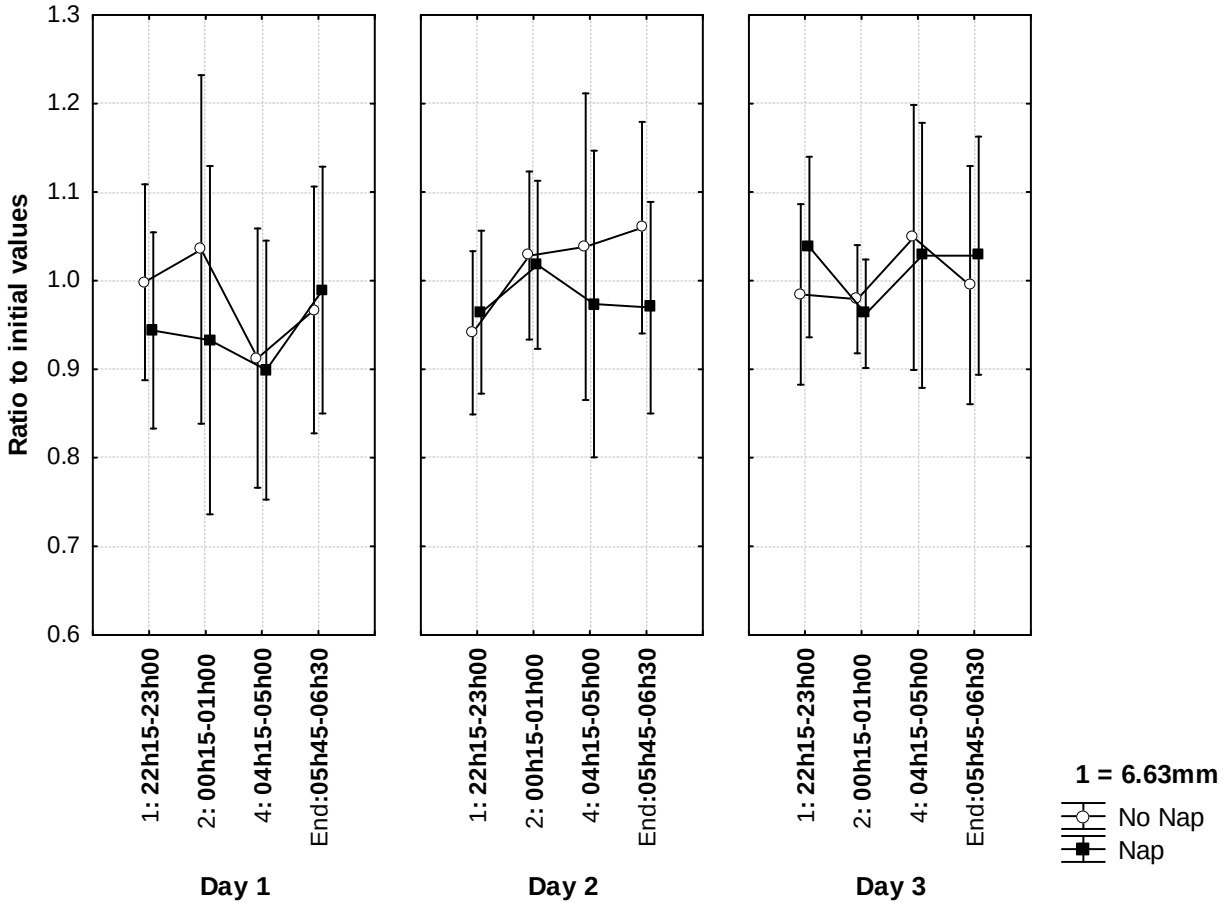

Figure 24**:** Low precision target deviation responses for both conditions over the three separate night shift. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Short term memory performance

Short term or working memory was assessed through the application of a simple word recall memory test (SWR): subjects were presented with twelve words for a 30 second memorising period, after which they had to recall as many words as possible after a 5 second delay. The score was the number of words correctly recalled.

Referring to the napping effect, *condition* failed to yield any significant differences in the number of words correctly recalled during the SWR over the three night shifts.

Circadian fluctuations did not significantly impact the measures over the course of the night shifts (*time effect*), but SWR scores were generally lower towards the end

of the night, compared to earlier tests (Figure 25). However, as evidenced in the reaction and precision response time data, the effect of the circadian upswing during the End-of-shift test (05h45 to 06h30) became apparent, resulting in an improvement in memory response. This however was not significant generally, but during the last night shift, the nap condition resulted in a gradual and consistent improvement in memory responses, demonstrating a significant *final effect*. No *roll-over* or *chronotype effects* were established.

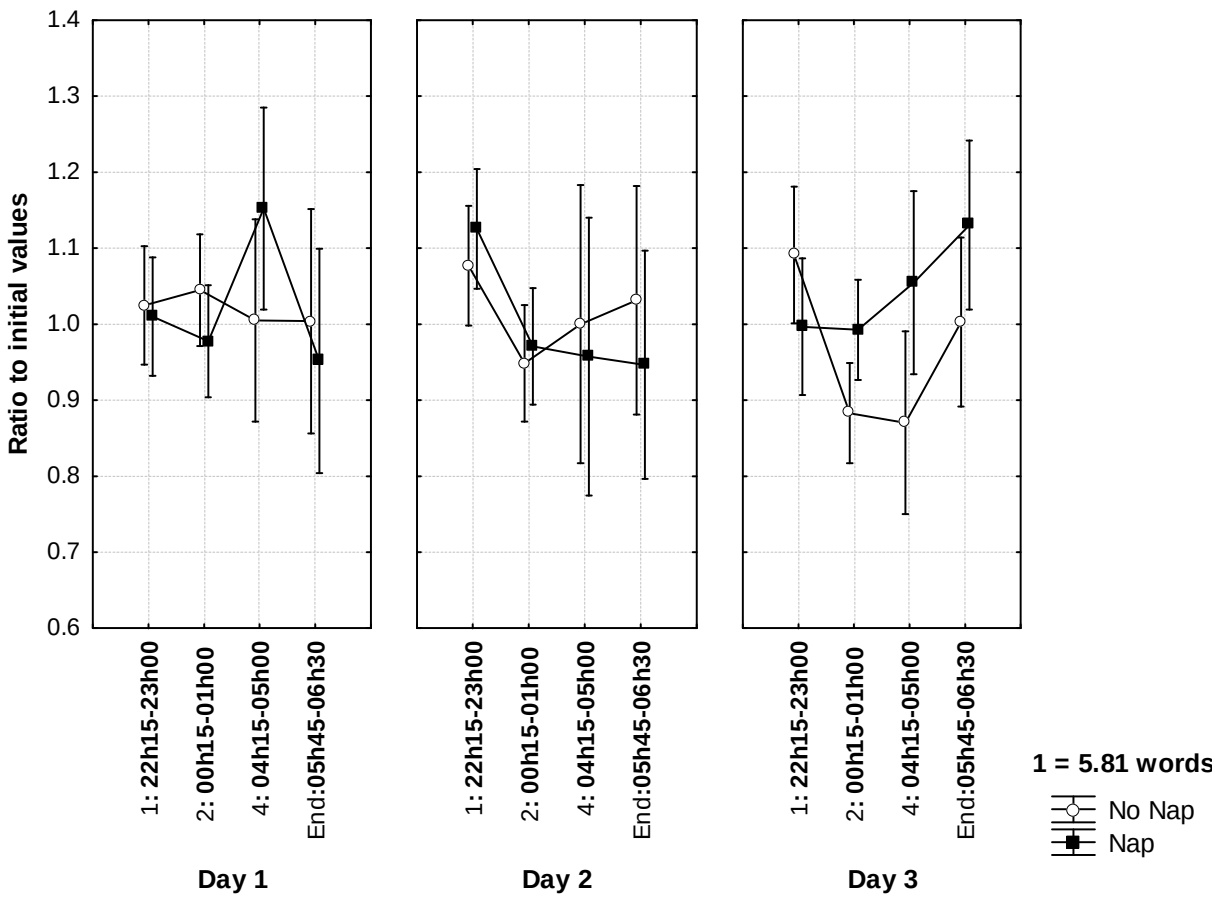

Figure 26**:** Simple word recall scores for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Table XIX**:** Statistical effects for Simple word recall test responses

	SS	Degrees of Freedom	MS	F	p
Condition	0.04	1,22	0.04	0.849	0.367
Days	0.018	2,44	0.009	0.209	0.812
Time	0.259	3,66	0.086	2.484	0.068
Days*Condition	0.125	2,44	0.063	1.469	0.241
Time*Condition	0.143	3,66	0.048	1.367	0.26
Days*Time	0.44	6, 132	0.073	2.149	0.052
Days*Time*Condition	0.365	6, 132	0.061	1.781	0.108
Condition*Chronotype	0.019	2,44	0.01	0.181	0.836
Final	0.204	1,22	0.204	5.043	0.035 *
Fatigue	0.001	1,22	0.001	0.013	0.909
Recovery	0.003	1,22	0.003	0.044	0.836

NEUROPHYSIOLOGICAL MEASURES

Critical flicker fusion frequency

Critical flicker fusion frequency (CFFF), specifically the ascending threshold was assessed using a pair of modified bifocal binoculars to determine the impact of the different conditions on the perception of flickering light and the frequency at which the flickering disappears. Overall, no *general effects* were found, with the nap failing to induce a significant effect on CFFF, when compared to the no nap condition (Table XX). No *final effects* were found either.

However, it is evident in Figure 27 that during all three shifts the nap (taken between Tests 2 and 4) resulted in a delay in the threshold perception, when compared to the no nap conditions. Despite this consistent pattern, there were no significant differences between the conditions in the data, which may have resulted from the strong variation in responses, which in turn may have been caused by the low number of subjects. *Chronotype* did not have an impact on the responses in anyway and no significant *rollover effects* were noted either.

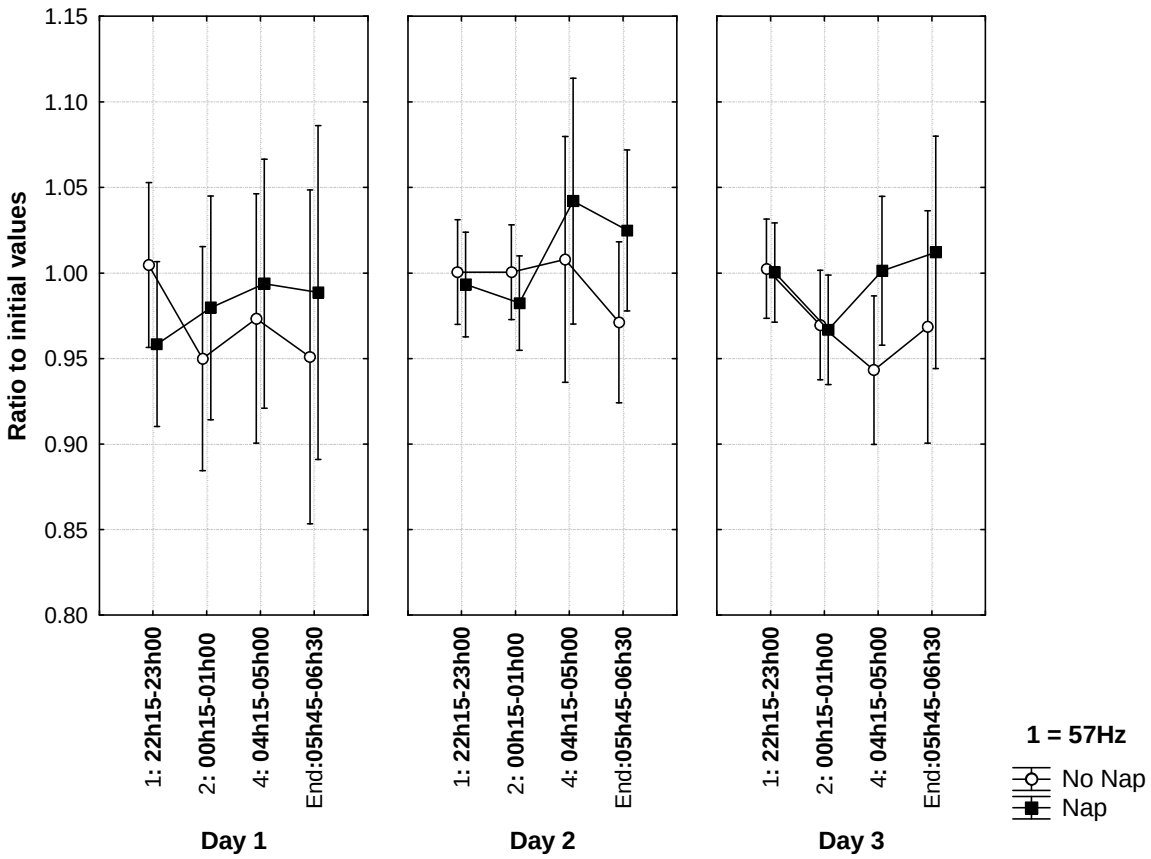

Figure 27**:** Critical flicker fusion frequency threshold responses for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and reflect a ratio to these initial reference values.

Table XX**:** Statistical effects for Critical flicker fusion frequency responses

	SS	Degrees of Freedom	MS	F	p
Condition	0.02	1,22	0.02	1.34	0.259
Days	0.04	2,44	0.02	1.54	0.226
Time	0.017	3,66	0.006	0.69	0.56
Days*Condition	0.002	2,44	0.001	0.09	0.914
Time*Condition	0.048	3,66	0.016	1.99	0.124
Days*Time	0.023	6, 132	0.004	0.53	0.788
Days*Time*Condition	0.017	6, 132	0.003	0.39	0.885
Condition*Chronotype	0.059	2,44	0.015	1.04	0.407
Final	0.031	1,22	0.015	1.607	0.216
Fatigue	0.042	1,22	0.042	1.684	0.208
Recovery	0.029	1,22	0.029	1.392	0.251

Saccade latency (High precision)

Saccade latency refers to rapid eye movements used to catch an image of interest on the fovea (Crevits et al., 2003). This response was assessed using the Dikablis Eye Tracker while the subjects performed two randomly ordered precision tasks. Saccadic velocities and latencies have been found to increase with time on task, but the results of the present study were to the contrary: saccade latency for the high precision task, for both conditions, tended to decrease during the course of the night, as displayed in Figure 28. This was not a significant *general effect* however (Table XXI).

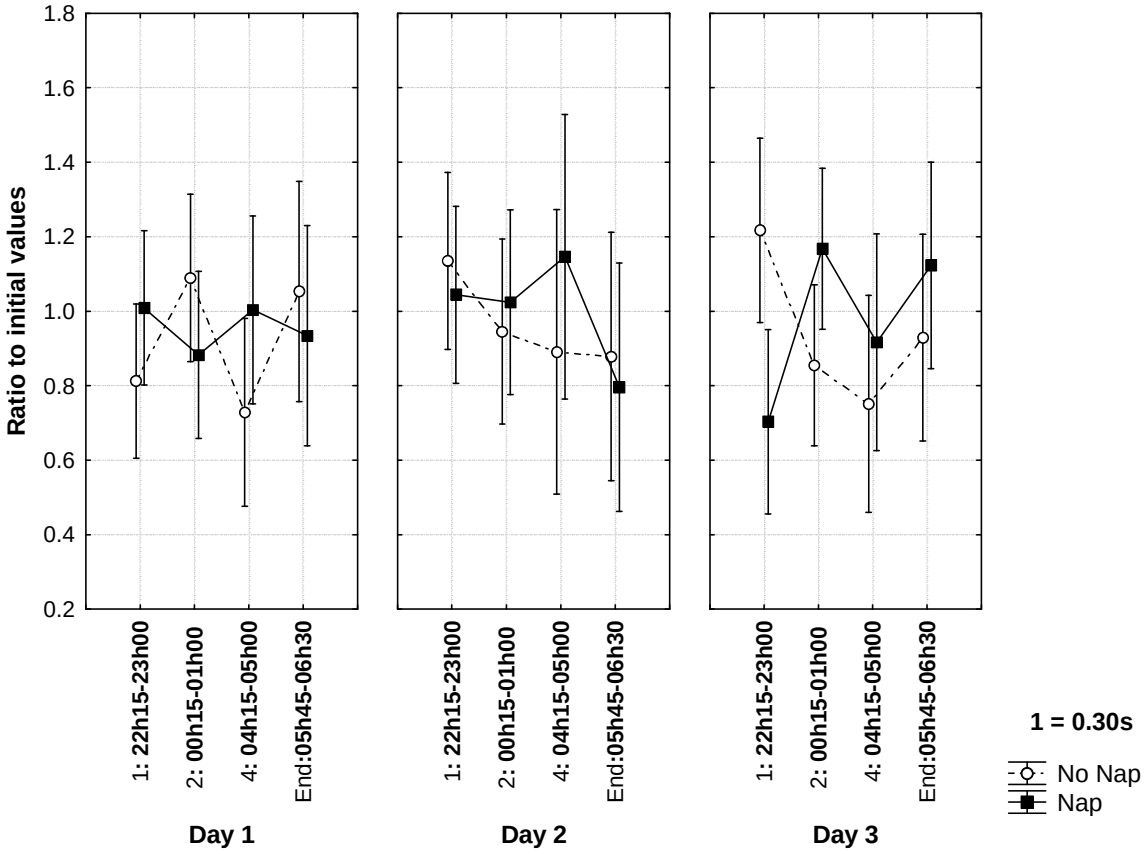

Figure 28**:** Saccade latency responses (High precision task) for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Further analyses revealed a three-way interaction effect between condition, time and days (p=0.033, Table XXI). The change in responses over the course of the four

tests each night was different for the nap condition (Figure 28), when compared to the no nap condition: napping resulted in increases in saccadic latency when compared to the no nap condition, the responses of which steadily declined throughout the night.

Table XXI**:** Statistical effects for Saccade latency responses during the high precision Fitts' task.

	SS	Degrees of Freedom	MS	F	p
Condition	0.109	1,22	0.109	0.509	0.483
Days	0.091	2,44	0.046	0.234	0.792
Time	0.348	3,66	0.116	0.482	0.696
Days*Condition	0	2,44	0	0.001	0.999
Time*Condition	1.263	3,66	0.421	1.75	0.165
Days*Time	1.286	6, 132	0.214	1.113	0.358
Days*Time*Condition	2.737	6, 132	0.456	2.369	0.033 *
Condition*Chronotype	1.165	2,44	0.582	3.596	0.09
Final	0.164	1,22	0.164	0.695	0.414
Fatigue	0.376	1,22	0.376	0.94	0.343
Recovery	0.906	1,22	0.906	2.231	0.149

Saccade latency (Low precision)

Condition elicited no effect on low precision saccade latency responses during any of the three night shifts. However, as seen in Figure 29 saccade latency responses did differ between the two conditions, with the nap condition following a natural and steady increase in saccade latency, possibly as a result of the natural circadian fluctuations, with pre-shift latency responses being consistently faster than post shift responses. No *final effects* or effect of *chronotype* were observed either.

Table XXII**:** Statistical effects for Saccade latencies (low precision task).

	SS	Degrees of Freedom	MS	F	p
Condition	0.42	1,22	0.42	1.44	0.243
Days	0.471	2,44	0.236	1.022	0.368
Time	0.342	3,66	0.114	0.59	0.624
Days*Condition	0.589	2,44	0.294	1.276	0.289
Time*Condition	0.683	3,66	0.228	1.177	0.325
Days*Time	0.515	6, 132	0.086	0.386	0.887
Days*Time*Condition	1.502	6, 132	0.25	1.126	0.351
Condition*Chronotype	0.057	2,44	0.029	0.089	0.915
Final	0.002	1,22	0.002	0.005	0.944
Fatigue	1.672	1,22	1.672	3.828	0.063
Recovery	2.232	1,22	2.232	5.295	0.128

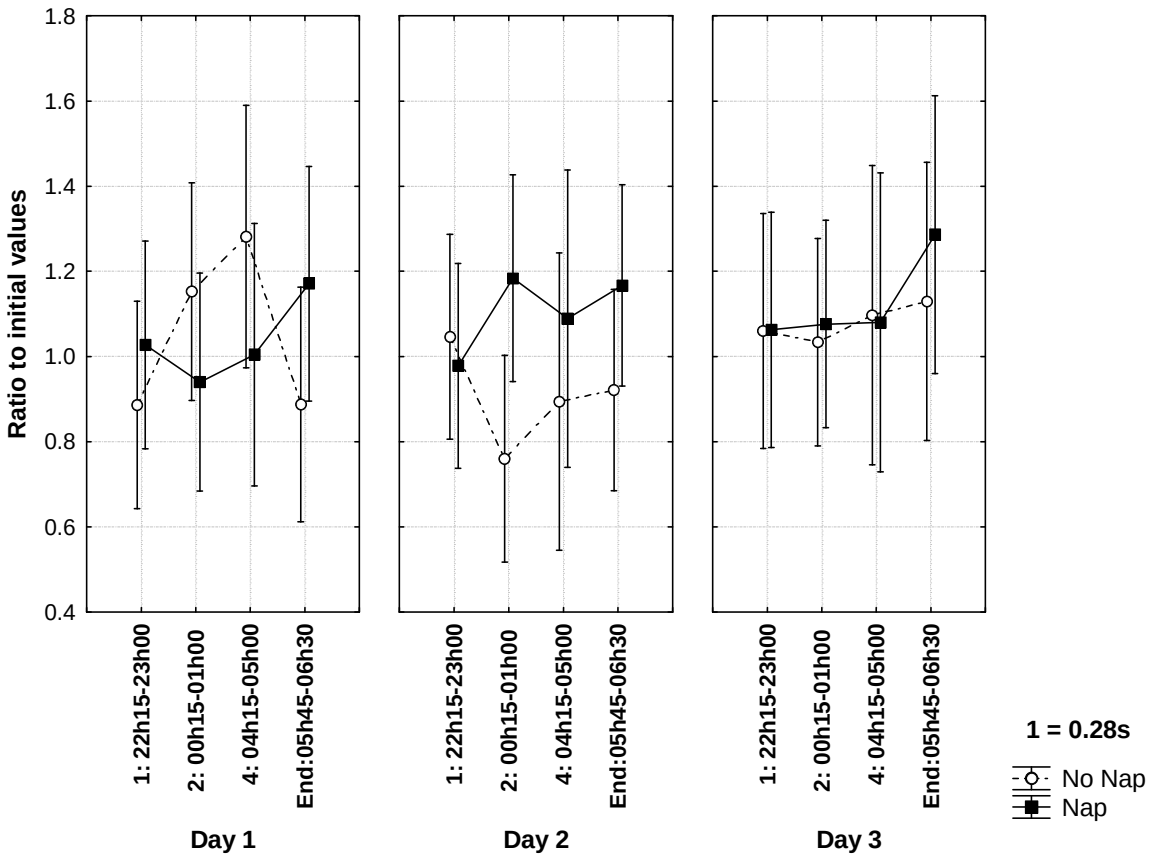

Figure 29**:** Saccade latency responses (Low precision task) for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values

SUBJECTIVE MEASURES

Subjective sleepiness: Karolinska Sleepiness Scale

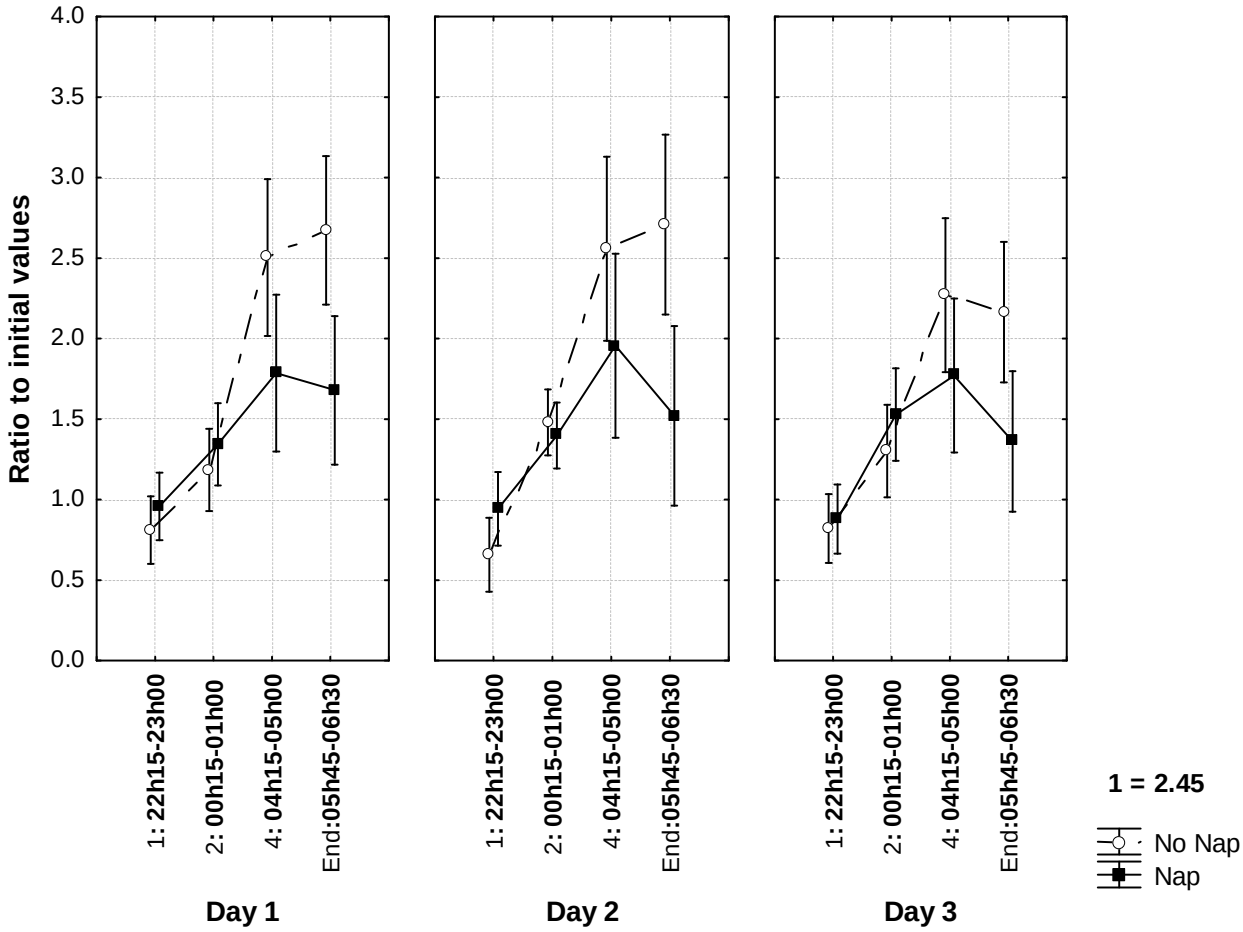

Figure 30**:** Karolinska Sleepiness Scale ratings for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Napping exerted a significant *condition effect* (p=0.017,Table XXIII) in reducing subjective sleepiness over the course of all the three night shifts: sleepiness ratings were significantly lower by the end of the shift for the nap group (3 day mean for test 4: 4.17±0.17), when compared to the no nap group (3 day mean for test 4: 4.19±0.22). Moreover, a significant *time effect* was found for subjective sleepiness measures over the course of the three night shifts, with these responses increasing considerably over the course of the night (Figure 30). No *final effects*, that indicate a

different level of sleepiness on third day, were observed. Finally, a significant interaction effect between *condition* and *time* was found, illustrating the effect of that the napping intervention had on the natural circadian-related changes in subjective sleepiness: lower sleepiness ratings were achieved throughout, when compared to those of the no nap group. *Chronotype* evoked no effect following additional analysis.

A general *roll-over effect* was established during the consideration of the Karolinska Sleepiness Scale ratings. As regards the *fatigue effect,* the inclusion of the nap condition resulted in significantly lower ratings of sleepiness, and thus lower *fatigue effect* over the course of the shift, compared to the ratings of the no nap group (Figure 31). Also the extent of the *fatigue effect* experienced by the napping group remained fairly consistent over the three nights. As for the *recovery effect,* the no nap group experienced a significantly higher recovery than did the nap group ($p<0.05$, Table XXIII). This was mainly due to the fact the sleepiness ratings were significantly higher at the end of each shift's final test, when compared to those of the nap condition.

Table XXIII**:** Statistical effects for subjective sleepiness responses (KSS)

	SS	**Degrees of Freedom**	**MS**	**F**	**p**
Condition	8.021	1,22	8.021	6.562	0.018 *
Days	1.024	2,44	0.512	0.934	0.401
Time	78.36	3,66	26.119	73.034	0.000 *
Days*Condition	0.253	2,44	0.127	0.231	0.795
Time*Condition	17.05	3,66	5.683	15.889	0.000 *
Days*Time	2.544	6, 132	0.424	1.466	0.195
Days*Time*Condition	0.803	6, 132	0.134	0.463	0.835
Condition*Chronotype	0.316	2,44	0.158	0.11	0.896
Final	1.495	1,22	1.495	2.343	0.14
Fatigue	18.3	1,22	18.298	28.901	0.000 *
Recovery	14.91	1,22	14.912	25.599	0.000 *

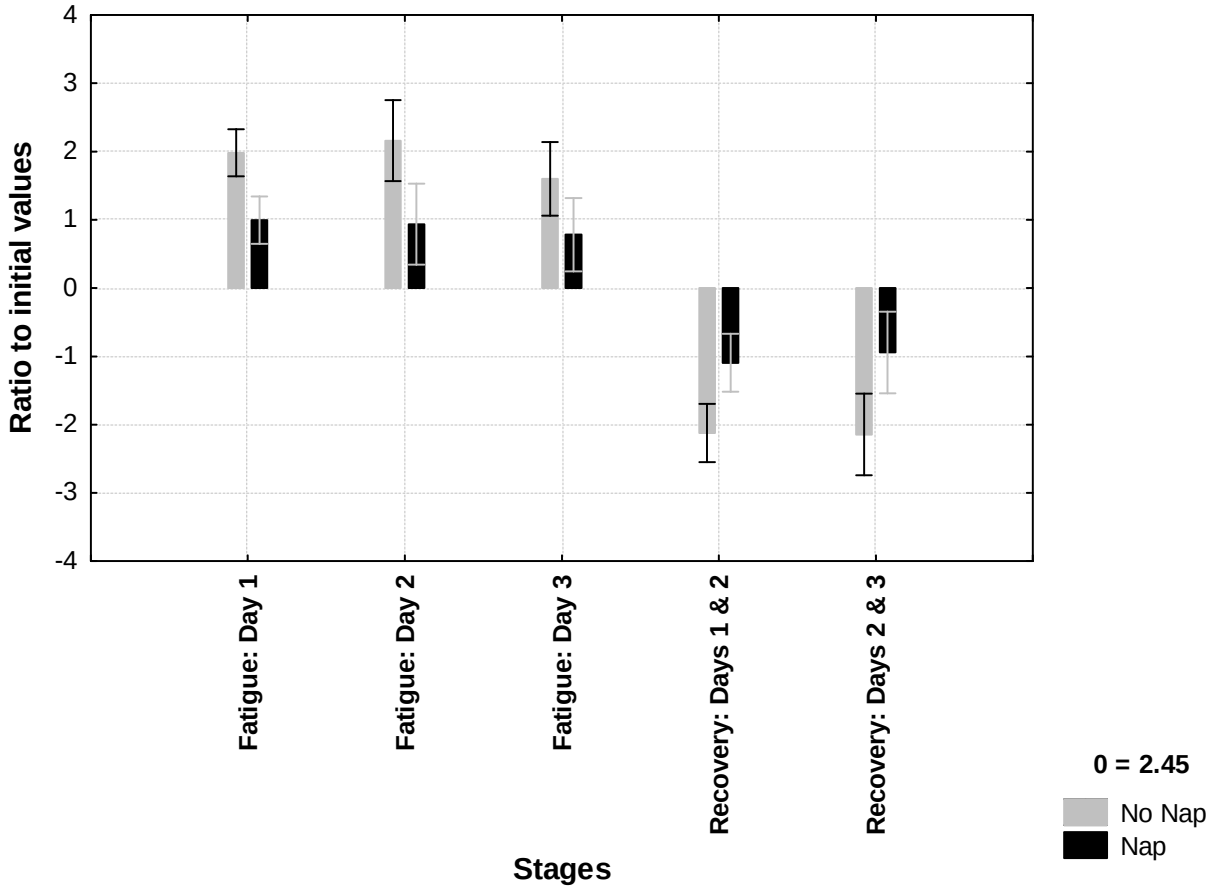

Figure 31**:** Fatigue and recovery effects for subjective sleepiness (KSS) responses during all three night shifts for both conditions. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

A further comparison of the night and day time responses was made: as illustrated in Figure 32, the no nap condition differed significantly from both the nap and day conditions, with sleepiness ratings being consistently higher over the course of each shift and over all three separate shifts. Further analyses confirmed that the nap condition did not differ significantly from the day shift, but sleepiness ratings were consistently higher during the night time (Appendix C, Table 5).

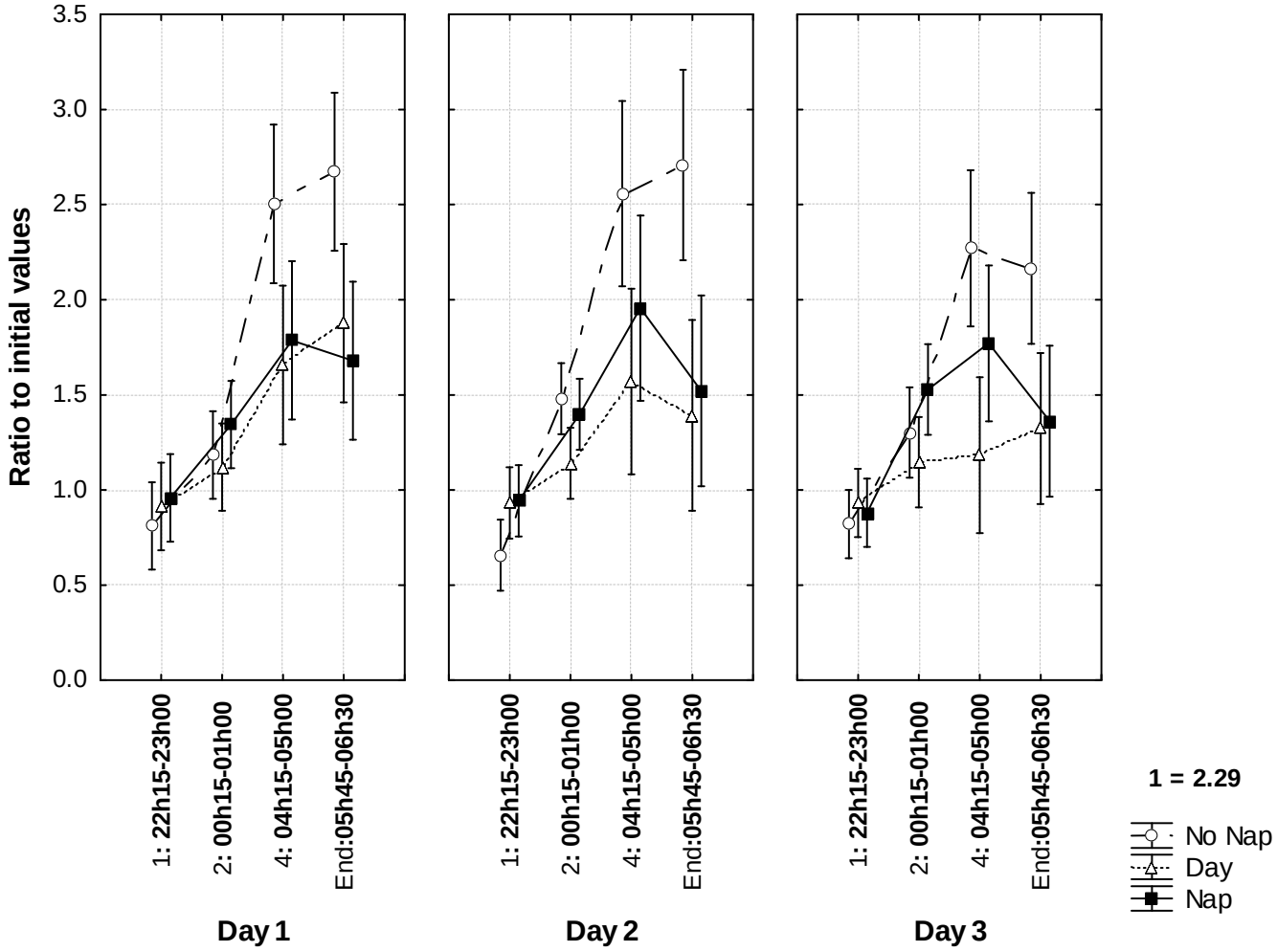

Figure 32**:** Karolinska Sleepiness Scale ratings for all conditions over the three separate testing nights and days. Note the testing times for the day shift were as follows: **1** = 08H15 to 09h00, **2** = 10h15 to 11h00, **4** = 14h15 to 15h00, **End of shift** = 15h45 to 16h30). All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Subjective sleepiness: Wits Sleepiness Scale

The Wits Sleepiness Scale (WSS) was used as an additional indicator of subjective sleepiness. Napping elicited a significant overall *condition effect* (p=0.005, Table XXIV) on sleepiness ratings over the three night shifts, with subjective sleepiness being significantly lower by the end of the shifts for the nap group, than for the no nap group (Figure 33). A significant *final effect* was also elicited (p=0.008), with napping evincing significantly reduced sleepiness ratings at the end of the third night shift, when compared to those of the no nap condition.

In addition to this, subjective sleepiness exhibited a *time effect*, with ratings peaking at Test 4 (04h15 to 05h00), which coincided with the circadian nadir. Finally, a significant *time and condition effect* was observed (p<0.05,Table XXIV). This indicates that the nap condition produced an effect on subjective sleepiness measures: through the alleviation of the circadian and homeostatic-related sleep pressure, the nap group's subjective perceptions of sleepiness may have been abated. No effect of *chronotype* was observed.

Table XXIV**:** Statistical effects for Wits Sleepiness Scale responses

	SS	Degrees of freedom	MS	F	P
Condition	5.555	1,22	5.555	9.987	0.005 *
Days	0.079	2,44	0.039	0.167	0.847
Time	40.4	3,66	13.468	54.645	0.000 *
Days*Condition	0.634	2,44	0.317	1.347	0.27
Time*Condition	8.88	3,66	2.96	12.011	0.000 *
Days*Time	1.211	6, 132	0.202	1.078	0.379
Days*Time*Condition	0.782	6, 132	0.13	0.696	0.653
Condition*Chronotype	1.099	2,44	0.55	0.963	0.401
Final	2.814	1,22	2.814	8.382	0.008 *
Fatigue	10.36	1,22	10.356	39.091	0.000 *
Recovery	5.442	1,22	5.442	13.148	0.001 *

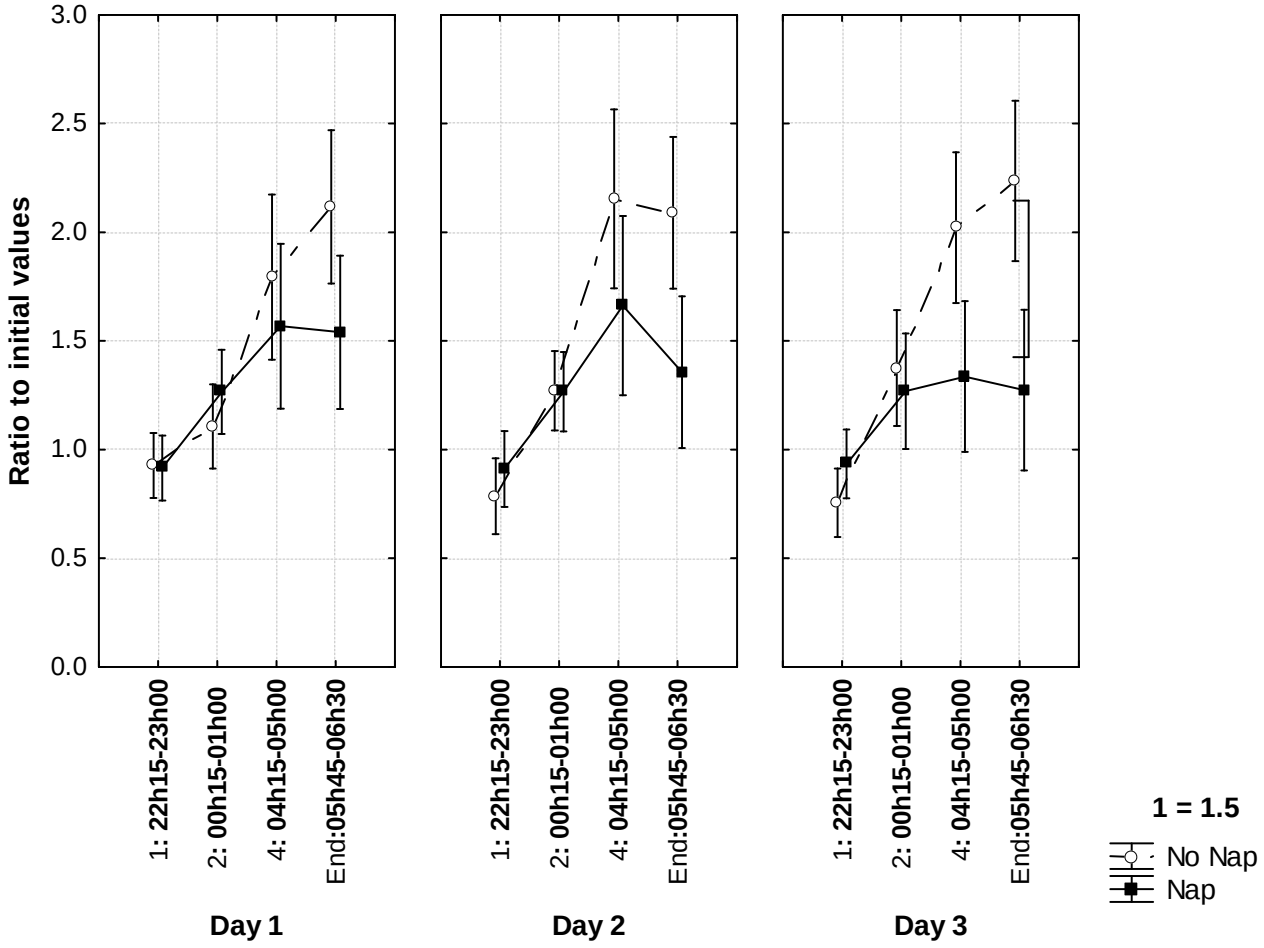

Figure 33**:** Wits Sleepiness Scale ratings for both conditions over the three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Upon further analysis, as shown in Figure 34, a general *roll-over effect* was found; the *fatigue effect* was significantly more apparent for the no nap group, than for the nap group, whose sleepiness ratings changed to a lesser extent over the shift than those of the no nap group. Additionally, the *recovery effect* for the no nap group was significantly better than for the nap group, but as with the Karolinska Sleepiness Scale, the significant differences between the End-of-shift tests and Pre-shift tests during the following nights for the no nap condition account for these differences.

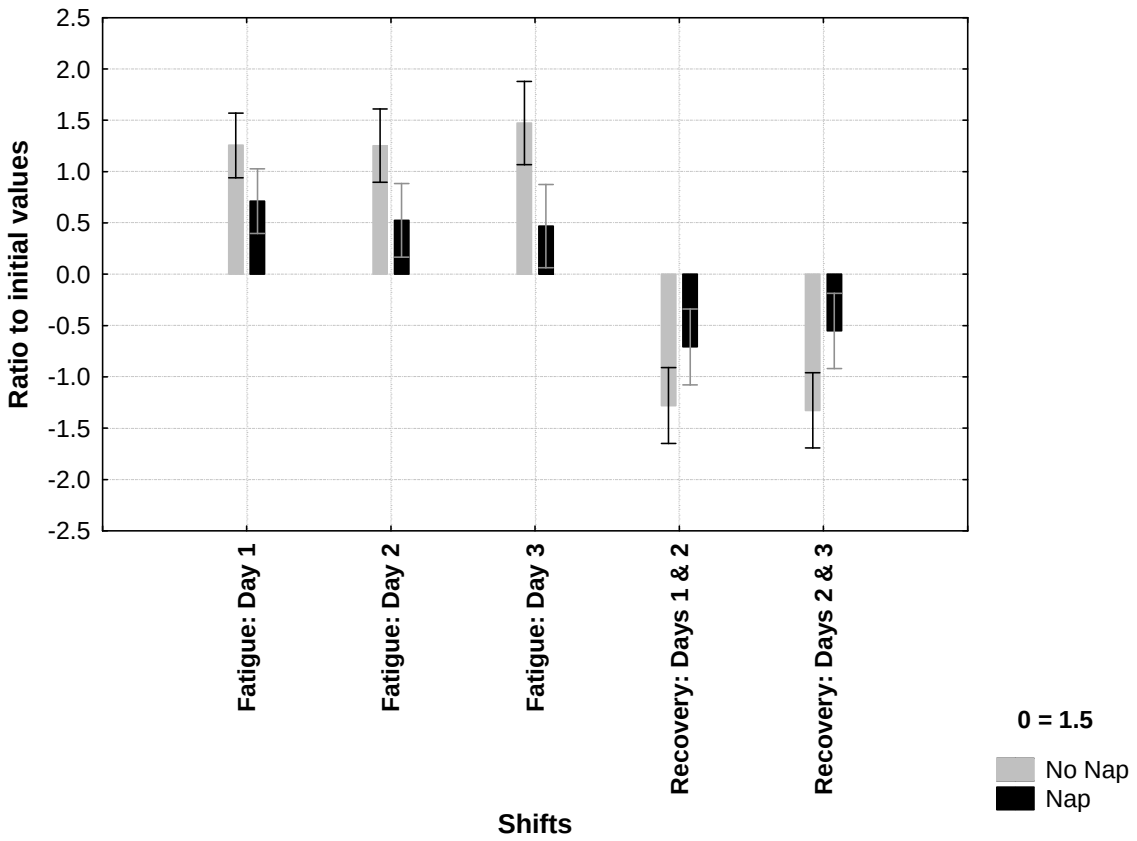

Figure 34**:** Fatigue and recovery effects for Wits Sleepiness Scale responses during all three night shifts for both conditions. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Finally, a comparison between the sleepiness ratings of the two night shift conditions and those of the day shift conditions revealed the following results: there were no significant *general effects* observed. However, at the end of all three night shifts the nap did elicit lower subjective sleepiness ratings, when compared to the day condition (Figure 35) but this difference was not significant (Appendix C, Table 6). Further analysis revealed a significant *final effect,* in that the day shift sleepiness ratings, when compared to the no nap condition, were considerably reduced by the end of the third shift.

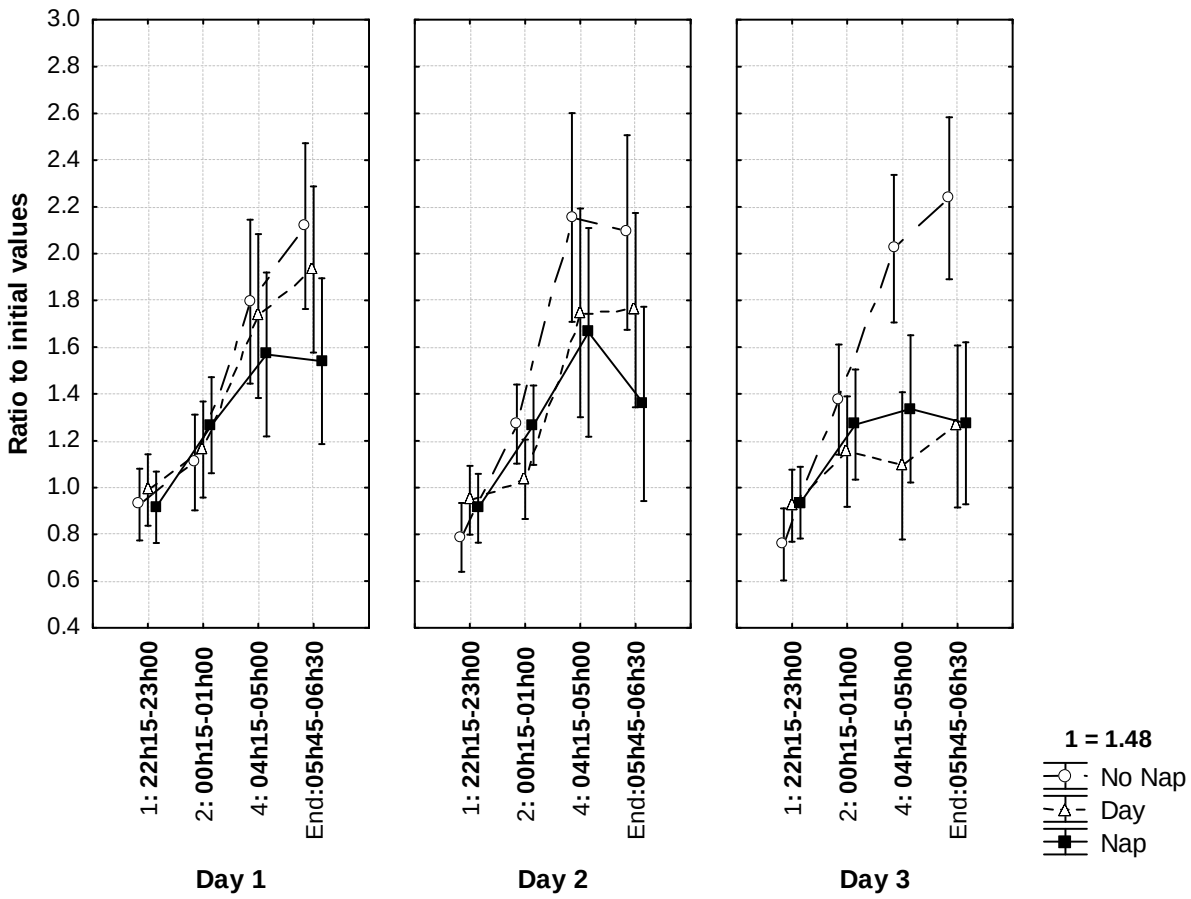

Figure 35**:** Wits Sleepiness scale ratings for all conditions over the three separate testing nights and days. Note the testing times for the day shift were as follows: **1** = 08H15 to 09h00, **2** = 10h15 to 11h00, **4** = 14h15 to 15h00, **End of shift** = 15h45 to 16h30). All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

GENDER EFFECTS

Considering that both male and female subjects were utilised in the current study, analyses were carried out to determine whether or not the condition effects differed according to gender. No significant gender effects, however, were found for the subject's responses to any of the variables, and in the interests of not broadening the study too much, no further analyses were carried out.

DIFFERENTIAL CONDITION EFFECTS

Poorest performance during the night shift

In an attempt to illustrate the impact of the unnatural working hours and the differential effects of the two night time conditions on each subject's responses during the various assessments, the lowest (poorest) point of each test's responses was identified. (Please refer to the paragraph below the Table XXV for further explanation).

Table XXV**:** Statistical effects for the lowest point of performance/response for each variable for both night conditions, including and excluding post-nap data. **Condition** = refers to the presence of a significant difference between the nap and no nap conditions either with or without the post nap data included in the analyses. **Days =** represents the significant differences between the two conditions over the three days of testing. This reflects the extent of adaptation, indicated by a reduction in the lowest point of performance/response. **Condition*Days interaction =** refers the significant differences between the two conditions over the course of three days of testing, specifically how the conditions alter the responses over the testing period. **The highlighted boxes represent statistically significant results. TTEMP**: Tympanic temperature; **STEMP:** Skin temperature; **HP RT** :High precision reaction time; **LP RT**: Low precision reaction time; **HPTD:** High precision target deviation; **LP TD**: Low precision target deviation; **SRT**: Simple reaction time; **SWR: Simple word recall test** ; **SL HP**: Saccade latency high precision; **SL LP**: Saccade latency low precision; **CFFF**: Critical flicker fusion frequency; **KSS**: Karolinska Sleepiness Scale; **WSS**:Wits Sleepiness Scale)

	With Post nap data			**Without Post nap data**		
	Condition	**Days**	**Condition*Days**	**Condition**	**Days**	**Condition*Days**
HPRT	0.088	0.058	0.126	0.545	0.283	**0.032**
HPTD	0.419	0.546	0.579	**0.006**	0.371	0.57
LPRT	**0.009**	0.24	0.318	0.648	0.522	0.263
LPTD	**0.004**	0.789	0.119	**0.000**	0.997	0.369
SWR	0.605	0.846	0.447	0.415	0.897	0.664
SRT	**0.003**	0.538	0.964	0.276	0.759	0.712
CFFF	0.555	**0.001**	0.901	0.691	0.34	0.864
SLHP	0.326	0.6	0.83	0.65	**0.000**	0.706
SLLP	**0.016**	0.927	0.478	0.118	0.52	0.458
TTEMP	0.708	**0.000**	0.295	**0.021**	**0.001**	0.712
STEMP	0.831	**0.004**	0.947	**0.024**	**0.001**	0.706
KSS	0.504	0.225	0.971	0.25	0.171	0.971
WSS	0.299	0.638	0.182	**0.029**	0.076	**0.038**

In order to achieve this, a comparison was made between all the shift tests (excluding test 3) in conjunction with the pre and post-nap data, and all the shift tests with just the pre-nap data. From a practical perspective, this section aims to illustrate how the inclusion of a nap when compared to no nap, may result in a temporary breakdown in performance immediately after the nap due to the effects of sleep inertia. In connection with this, since the post nap test occurred immediately after the nap ceased, the effects of sleep inertia would be expected to be most pronounced at this point. Those responses with significant effects when the post-nap responses were considered will be discussed, with reference to Table XXV.

Low precision response time

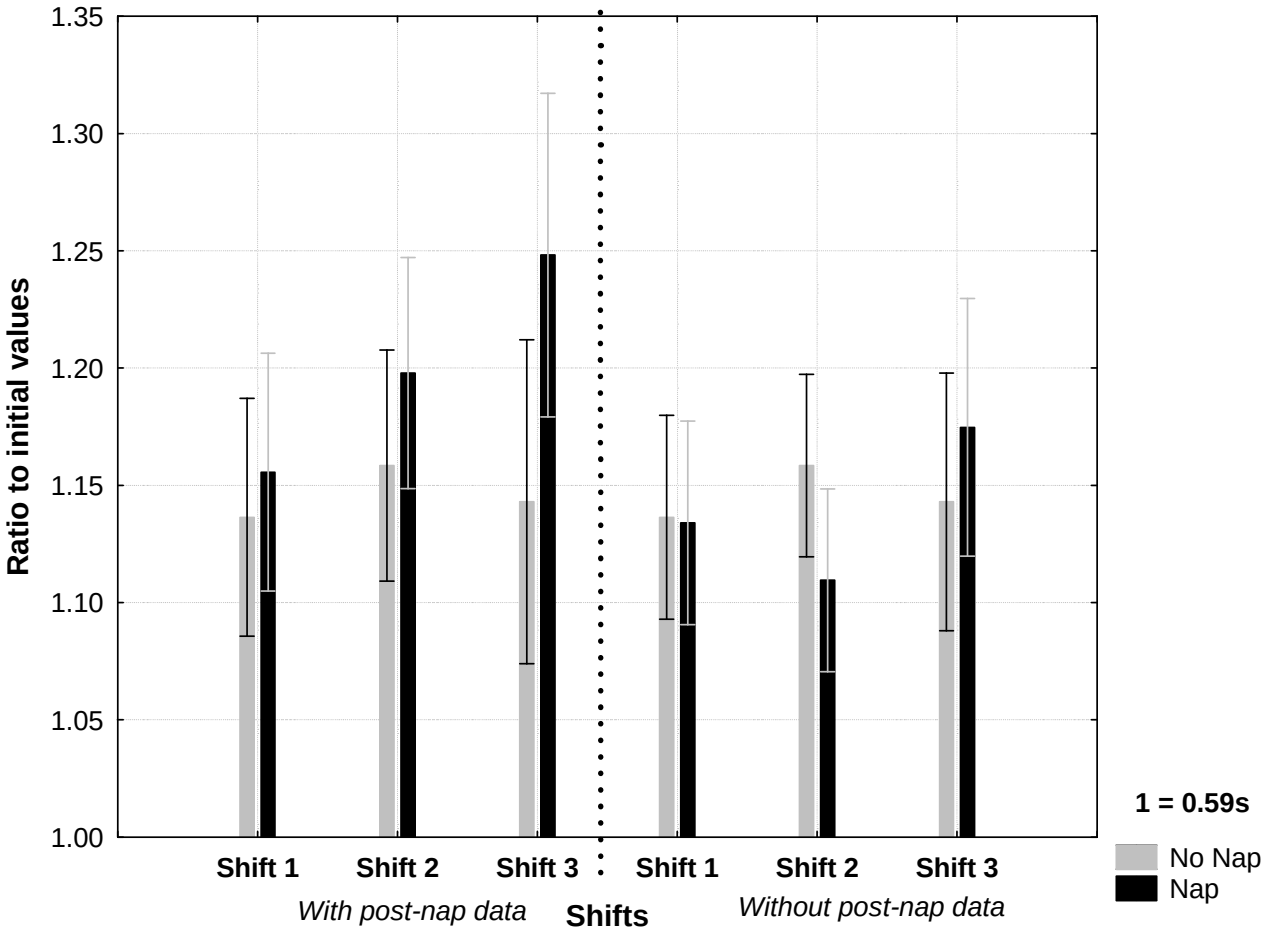

Figure 36: Comparison of worst low precision response times for both conditions during all three separate night shifts.

Figure 36 illustrates for both conditions, the lowest point of performance. When the post-nap data were considered, napping elicited significantly worse response times from the nap group than from the no nap group (p=0.009,Table XXV). The latter group's poorest average performance remained consistent over the three shifts, whereas the nap group's average worsened over time. This may have been the product of more pronounced effects of sleep inertia following the nap. However, when the post-nap data were not considered, the lowest point of performance for both conditions did not differ significantly: in fact during shift 2, the poorest response time of the nap group was better than that of the no nap group.

Low precision target deviation

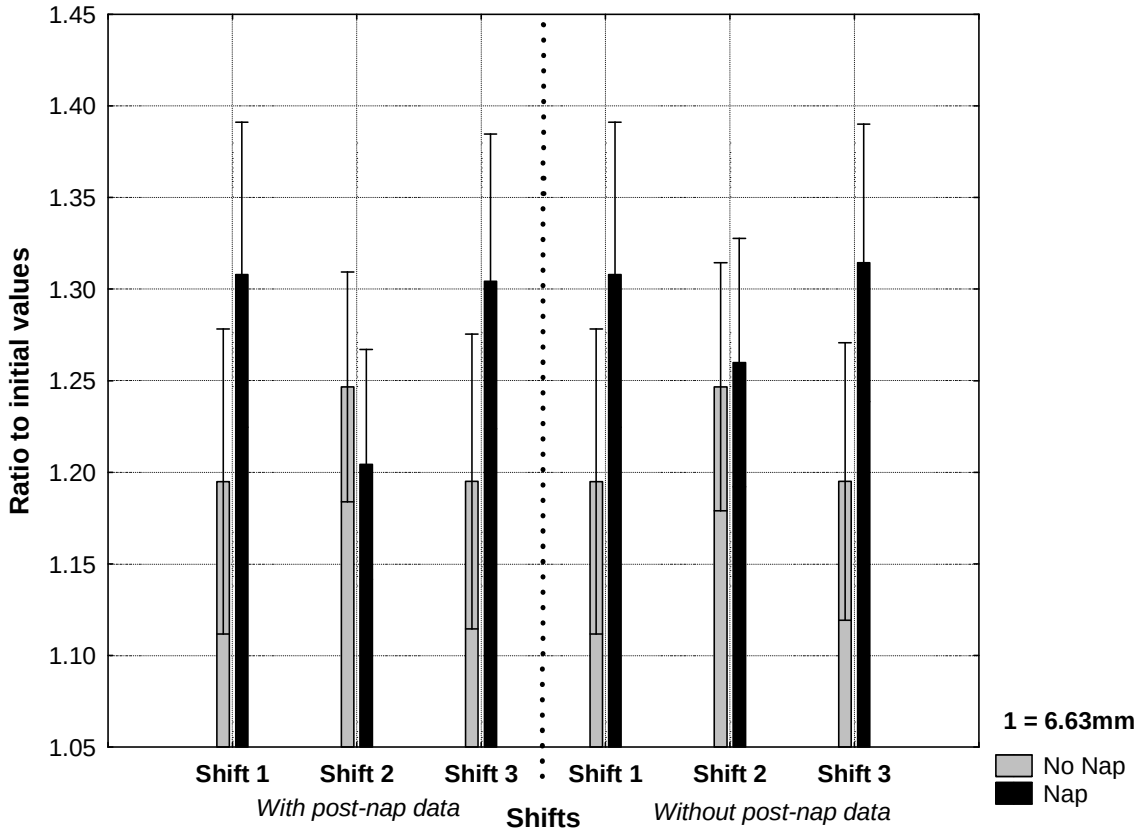

Figure 37**:** Comparison of worst target deviation responses (Low precision) for both conditions during all three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

Target deviation responses during the low precision Fitt's tapping task were significantly worse for the nap than the no nap subjects (Figure 37). However, the exclusion of the post-nap data did not alter the trend of responses: significantly larger target deviations were observed for the nap group than the no nap group, indicating that possible sleep inertia from the nap did not necessarily have an impact on poorest target deviation responses (Table XXV).

Simple reaction time

Longer reaction time responses were evinced in the nap group when compared to the no nap group (Figure 38). Reaction times responses, in the case of the nap condition, were adversely affected by the inclusion of the post-nap data, demonstrating the marked impact that the resultant sleep inertia from the nap, had on the group's responses. When the post-nap data were not considered, there were no significant differences between the two conditions with regard to poorest reaction time responses.

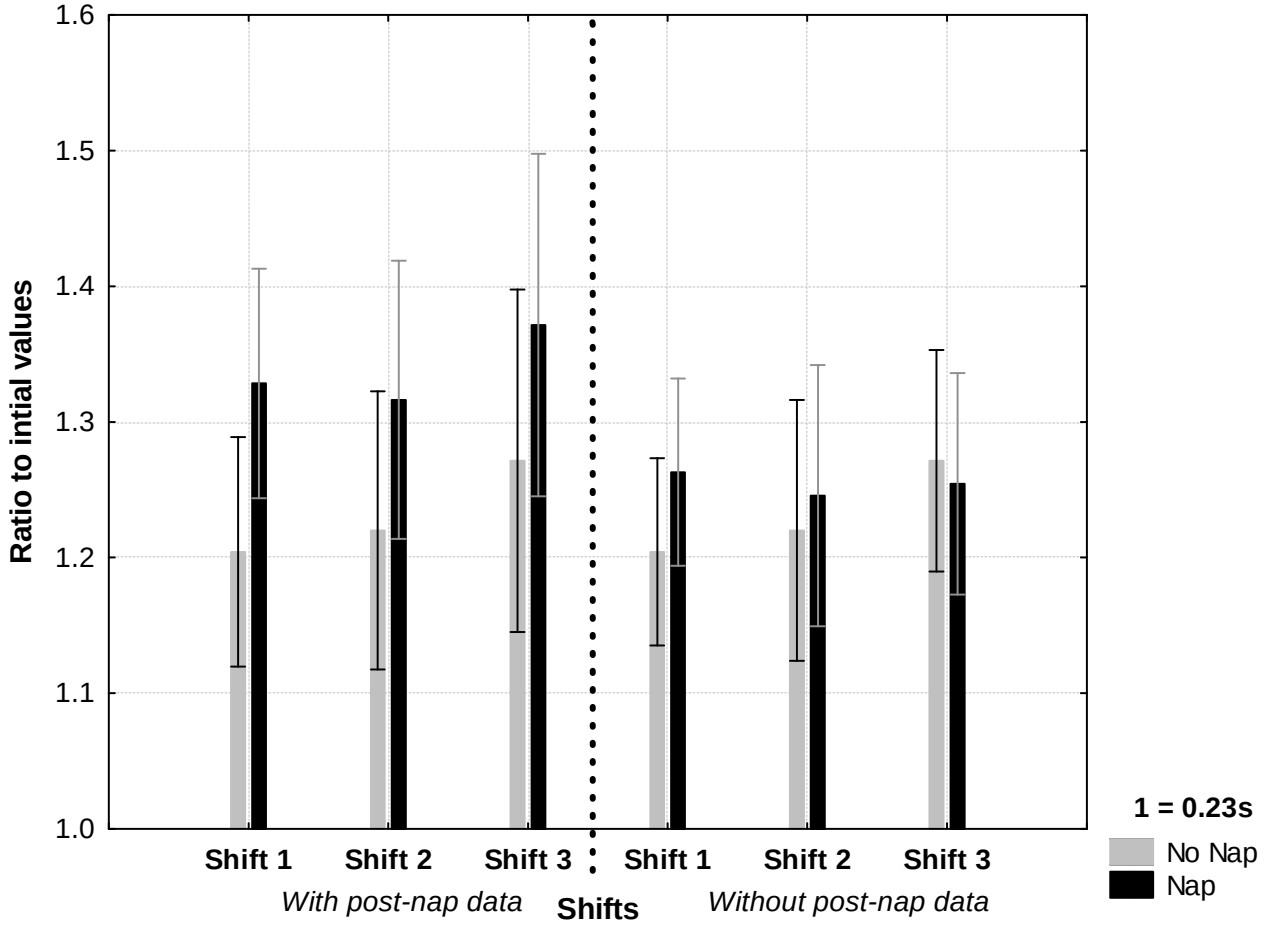

Figure 38**:** Comparison of worst simple reaction time responses for both conditions during all three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values

Saccade latency (low precision)

Following the inclusion of post-nap data, the nap condition elicited significantly slower saccadic latencies during the low precision Fitt's tapping task, when compared to the no nap group. Referring to the graph below (Figure 39), it is evident that the inclusion of the post-nap data demonstrates that for the nap condition, the period just after waking does result in poorer performances and responses; the exclusion of the post-nap data yielded much less severe response decrements when

compared to the responses from the no nap condition, with the responses from both conditions not differing significantly (Table XXV).

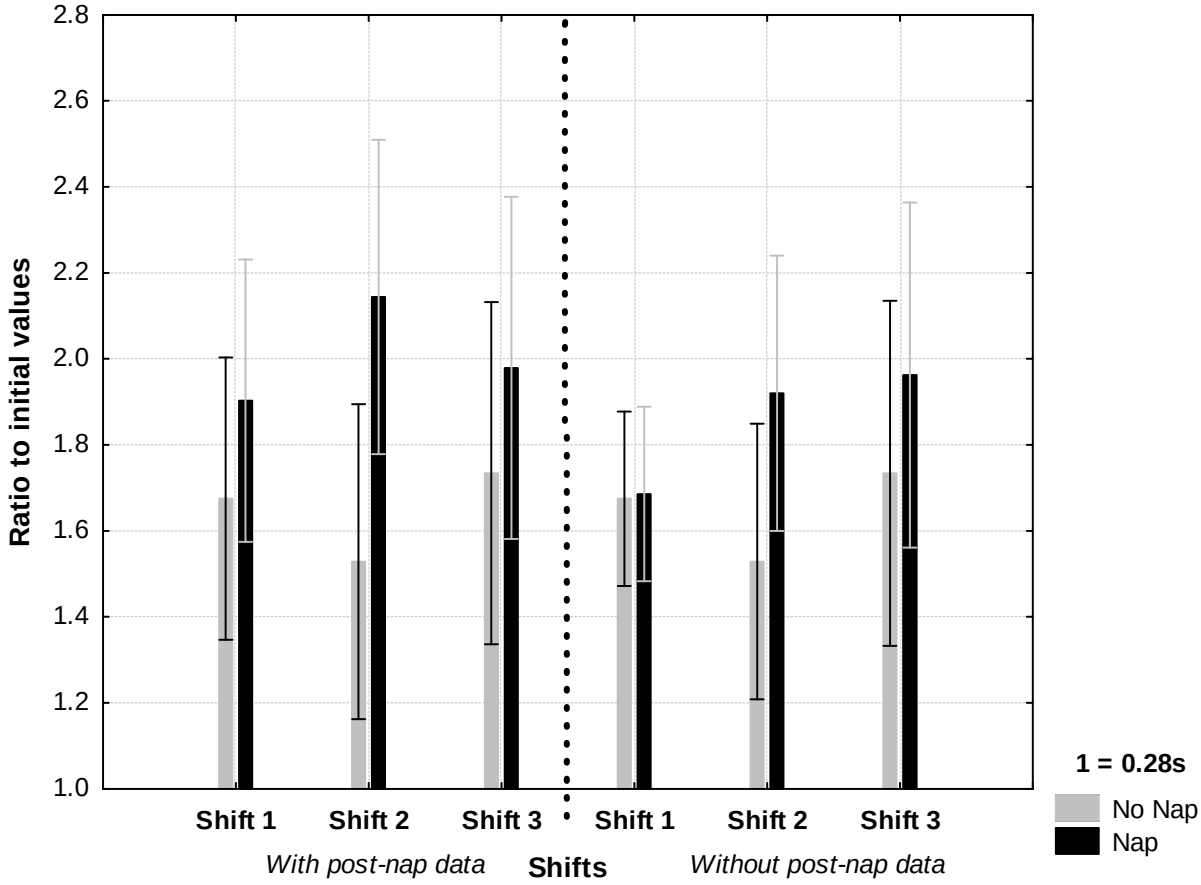

Figure 39**:** Comparison of worst saccadic latency responses (low precision) for both conditions during all three separate night shifts. All data expressed in the Figure were referenced to the pre-shift test, test 1 and test 2 of the first day and therefore reflect a ratio to these initial reference values.

NAPPING EFFECTS

This section focused on the descriptive statistics of the nap (length and timing) and the impact of performance and response fluctuation on nap timings. In addition to this, pre-nap and post-nap test comparisons facilitated insights into the presence and the effects of sleep inertia after the nap. Correlations between this data and the perceived sleep quality and length were performed to determine whether

performance/response change after the nap was dependent on the perceived length or quality of the nap.

Perceived sleep length and timing

Twelve subjects were afforded a 1 hour flexible nap between the hours of 00h00 and 03h00. Perceived sleep length decreased significantly (Table XXVI) over the course of the three nights. In addition to this, the time at which the naps were taken tended to be later on days 2 and 3 than on day 1. A one-way Analysis of Variance revealed no significant differences between the nap timings or their perceived quality over the three shifts, as illustrated in Table XXVI.

Table XXVI**:** Average perceived sleep length and nap timing for all three night shifts (*denotes significant differences between days)

	Day 1	**Day 2**	**Day 3**
Perceived length (minutes)	35.8 (±16.8) *	29.2 (±10.6) *	17.5(±19.2) *
Perceived quality	3.42 (±0.9)	3.42 (±1.01)	2.8 (±1.75)
Nap timing	02h22(±27:05)	02h37(±16:22)	02h38 (±13:37)

Nap timing and performance fluctuation (Pre-nap test & Test 2)

In an attempt to demonstrate the link between a certain extent of performance breakdown and the choice by the subjects to nap, a correlation was made between nap timing and the performance fluctuation between Test 2 (a fixed test, 00h25 to 01h00) and the Pre-nap test (as chosen by the subjects). As illustrated in Table XXVII, a number of correlations were found between nap timing and performance oscillation, specifically tympanic temperature, high and low precision task deviation, and subjective sleepiness measured by the Karolinska Sleepiness Scale. These results indicate that during this particular shift, the timing at which that the naps occurred may have been dependent on the degree of performance breakdown in terms of the above mentioned factors. No real trends were observed during the subsequent shifts.

Table XXVII**:** Correlation between performance/response fluctuation (Pre nap – Test 2) and the timing of the nap for all variables. The grey fields represent significant correlations between the performance and response fluctuations and nap timing.

Variable	Shift 1	Shift 2	Shift 3
Tympanic temperature	-0.66	0.15	0.04
Skin temperature	-0.45	0.32	0.67
High precision response time	-0.19	0.28	0.37
High precision target deviation	-0.70	0.26	-0.17
Low precision response time	-0.17	-0.16	0.31
Low precision target deviation	-0.77	0.06	-0.22
Simple reaction time	-0.38	-0.52	0.14
Simple word recall test	0.37	-0.33	-0.37
Critical flicker fusion frequency	0.00	0.46	-0.21
Saccade latency (HP)	0.10	0.14	0.71
Saccade latency (LP)	-0.47	-0.05	0.06
Karolinska sleepiness scale	0.57	0.07	0.18
Wits sleepiness scale	0.43	-0.54	0.03

Nap timing and performance fluctuation (Test 4 - Test 2)

An analysis was performed on the extent to which sleep inertia, as evidenced by the deterioration in performance between Test 4 and Test 2, was dependent on or correlated to the time at which the subjects chose to nap. Referring to Table XXVII during the first night shift, it was found that the timing of the nap may have been dependent on fluctuations in skin temperature, heart rate frequency and variability, the low frequency component of heart rate variability and the low frequency/high frequency ratio. In addition to these, nap timing also tended to coincide with a decrease in high and low target deviation, and lastly, memory performance, which was positively correlated with the timings of the nap. The other shifts did not yield any definitive patterns.

Table XXVIII: Correlation between performance fluctuation (Test 4 – Test 2) and the timing of the nap for all variables. The grey fields represent significant correlations between the performance and response fluctuations and nap timing).

Variables	Shift 1	Shift 2	Shift 3
Tympanic temperature	-0.10	0.17	-0.03
Skin temperature	-0.54	0.31	0.01
Heart rate frequency	-0.51	0.30	0.27
Heart rate variability	-0.51	0.29	-0.06
High frequency power	0.22	0.04	0.61
Low frequency power	-0.51	-0.17	0.16
Low/high frequency ratio	-0.58	-0.04	0.12
High precision response time	-0.04	0.18	0.20
High precision target deviation	-0.52	0.07	0.33
Low precision response time	0.22	-0.16	0.19
Low precision target deviation	-0.64	0.08	-0.14
Simple reaction time	-0.23	0.18	0.74
Simple word recall test	0.43	-0.37	0.05
Critical flicker fusion frequency	-0.10	0.67	0.01
Saccade latency (HP)	-0.02	-0.02	0.64
Saccade latency (LP)	-0.40	0.00	0.33
Karolinska sleepiness scale	0.21	0.30	0.07
Wits sleepiness scale	0.32	0.25	0.05

Nap timing and beading performance

Across all three night shifts, absolute beading performance (which refers to the number of beads produced by each subject at the end of each shift) correlated positively with nap timing, with Day 2 producing the only significant correlation (r=0.54, Table XXIX). However, considering the correlation coefficients of r=0.32 and r=0.39 for first and third shift, one might speculate that it would be possible to establish significant effects with a larger sample size. Generally, it was observed that individuals that napped later tended to thread more beads by the end of the shift, when compared to individuals that had napped earlier (Figure 40).

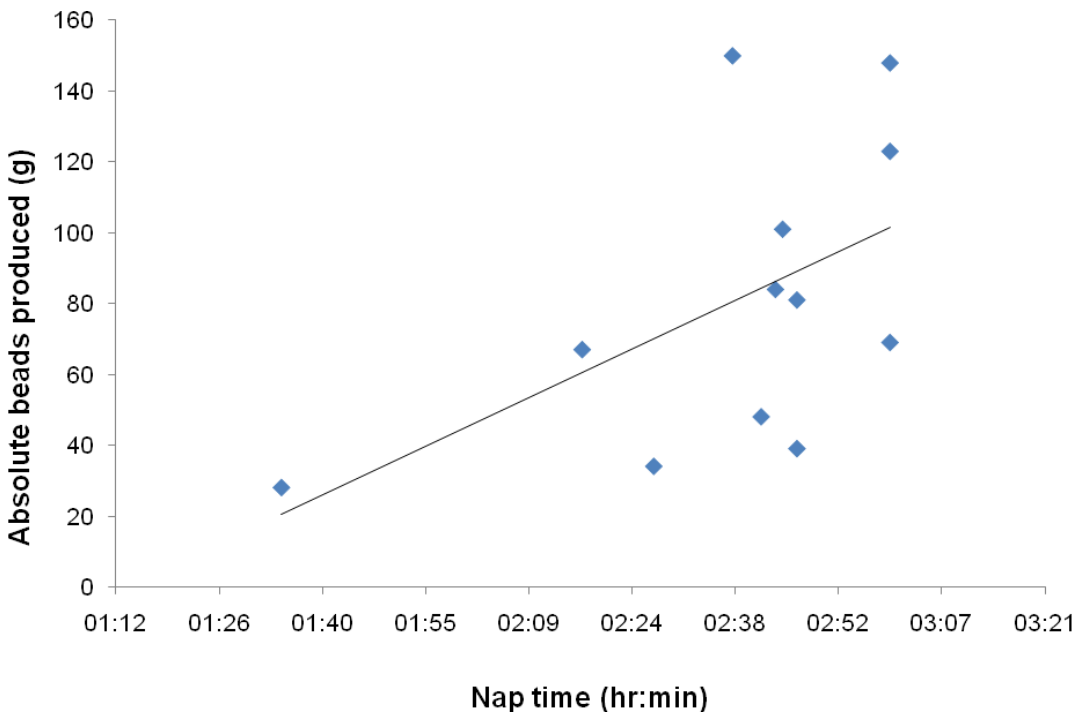

Figure 40**:** Correlation between nap timing and absolute beads produced by the end of shift on Night 2 only.

Table XXIX**:** Correlation between absolute beading performance by the end of the shift and nap timing.

Shift 1	Shift 2	Shift 3
0.315254	0.535796758*	0.387106662

Beading performance during the napping period

Total beading performance between Test 4 and Test 2 (3 hours of working time for both conditions) was calculated to determine the impact of the nap on production when compared to the no nap condition (Test 4 – Test 2). No significant *condition effects* were observed over the course of the three nights: as demonstrated in Figure 41, the nap group produced fewer beads per hour over the first two nights, but improved upon the performance of the no nap group by day 3. There was however a notable *day effect* (Table XXX) absolute beading performance increased significantly

over the course of the three-night shift cycle, which can be explained by the subject adaptation to the irregular work hours and familiarisation with the task requirements.

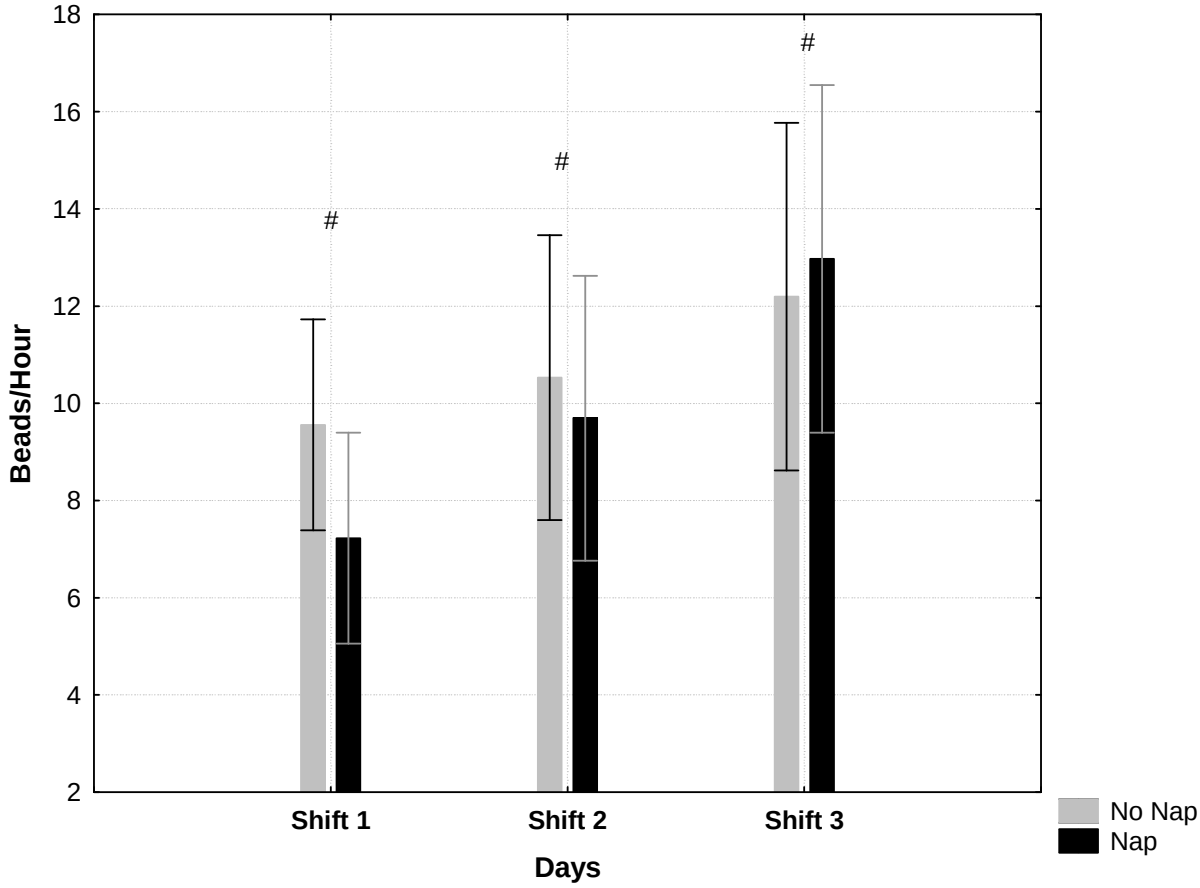

Figure 41**:** Beading performance (beads per hour) between Test 4 and Test 2 for both conditions (# denotes a significant *day effect*).

Table XXX: Statistical effects for beading performance between Test 4 and Test 2 (* denotes a significant difference)

	SS	**Degrees of Freedom**	**MS**	**F**	**p**
Condition	11.414	1, 22	11.414	0.218	0.645
Days	213.370	2,44	106.685	10.369	0.000*
Days *Condition	29.049	2,44	14.525	1.412	0.255

Pre-nap and Post-nap comparison (Sleep inertia)

Reponses during the post-nap tests for high and low precision response time, simple reaction time, memory performance and subjective sleepiness (WSS) were significantly reduced when compared to those of the pre-nap tests (Post-nap test – Pre-nap test). Since little was known about the quality and *actual* (as opposed to perceived) length of the sleep during the nap, it was assumed that the decrements in performance and the increase in subjective sleepiness were due to the presence of sleep inertia following the nap.

Table XXXI: Statistical effects all variables displaying the effects of sleep inertia. The grey highlighted fields represent statistical significances between pre-nap and post-nap data over the three days (**Days effect**), between the two measures (**Time effect**). It also reflects the change in the measures over the course of the three days of testing (**Days*measures interaction**).

	DAYS	TIME	DAYS*MEASURES
High precision response time	0.04	0.00	0.60
High precision target deviation	0.66	0.56	0.75
Low precision response time	0.13	0.00	0.56
Low precision target deviation	0.91	0.83	0.89
Simple reaction time	0.65	0.00	0.91
Simple word recall test	0.66	0.01	0.72
Critical flicker fusion frequency	0.54	0.12	0.71
Saccade latency (HP)	0.87	0.58	0.74
Saccade latency (LP)	0.49	0.77	0.89
Karolinska sleepiness scale	0.54	0.12	0.71
Wits sleepiness scale	0.19	0.03	0.36

Differences between pre-nap and post-nap responses and perceived sleep length

In order to determine the effect of perceived sleep length on the extent of performance breakdown after the nap relative to the test before the nap, a correlation was run between the pre and post nap test differences and the perceived sleep length of the nap. No significant effects were found, indicating that the

perceived sleep length was not considered to have had an impact on the extent of performance/responses difference during the nap.

Table XXXII**:** Correlation between perceived sleep length and the differences between pre-nap and post-nap responses during all tests administered.

	Shift 1	**Shift 2**	**Shift 3**
High precision response time	0.32	-0.04	-0.37
High precision target deviation	0.40	0.07	0.32
Low precision response time	-0.02	-0.02	-0.05
Low precision target deviation	-0.22	0.07	-0.38
Simple reaction time	0.11	-0.19	-0.18
Simple word recall test	-0.16	0.27	0.34
Critical flicker fusion frequency	0.44	-0.33	-0.11
Saccade latency (HP)	-0.07	0.10	-0.10
Saccade latency (LP)	-0.12	0.37	-0.27
Karolinska sleepiness scale	0.44	-0.33	-0.11
Wits Sleepiness Scale	0.34	-0.03	-0.17

Differences between pre-nap and post-nap test responses and perceived sleep quality

An attempt was made to determine whether a relationship existed between the subject's perceived quality of sleep during the nap and deterioration in performance that occurred as a result of the nap. This was calculated by correlating each subject's perceived sleep quality with the differences in the post nap performance and responses, relative to the pre nap values. (Table XXXIII). No definitive patterns were observed.

Table XXXIII**:** Correlation between perceived sleep quality and the difference between pre-nap and post-nap responses during all tests administered. The grey fields represent significant correlations between the perceived sleep quality and the pre-post nap differences.

	Shift 1	**Shift 2**	**Shift 3**
High precision response time	-0.37	-0.26	-0.33
High precision target deviation	-0.49	0.63	0.50
Low precision response time	-0.16	-0.44	0.38
Low precision target deviation	0.12	-0.11	-0.08
Simple reaction time	-0.12	-0.54	0.23
Simple word recall test	-0.12	-0.52	0.13
Critical flicker fusion frequency	-0.17	0.18	-0.52
Saccade latency (HP)	0.10	0.00	0.35
Saccade latency (LP)	-0.14	0.36	-0.12
Karolinska sleepiness scale	-0.17	0.18	-0.52
Wits Sleepiness Scale	-0.36	-0.24	-0.27

SLEEP DIARY RESPONSES

This final section will focus specifically on the data collected from the sleep diaries that the subjects completed during the three days before testing, the three days of testing and the three days after their test period. Of particular interest were the recovery sleep duration differences between the two experimental conditions (nap and no nap) over this period as well as the perceived quality of sleep and the number of disturbances during the recovery sleep.

Recovery sleep duration before, during and after shift work exposure

Figure 42 illustrates the recovery day sleep experienced by the nap group compared to the no nap group, as recorded in the 9-day sleep diary. All data were referenced to the mean of the first three pre-test days. During the three days of testing, recovery sleep was significantly shorter for both conditions, when compared to sleep on the three days before and the three days after the testing (Table XXXIV). The nap group tended to have a shorter recovery sleep than the no nap group, but not significantly so.

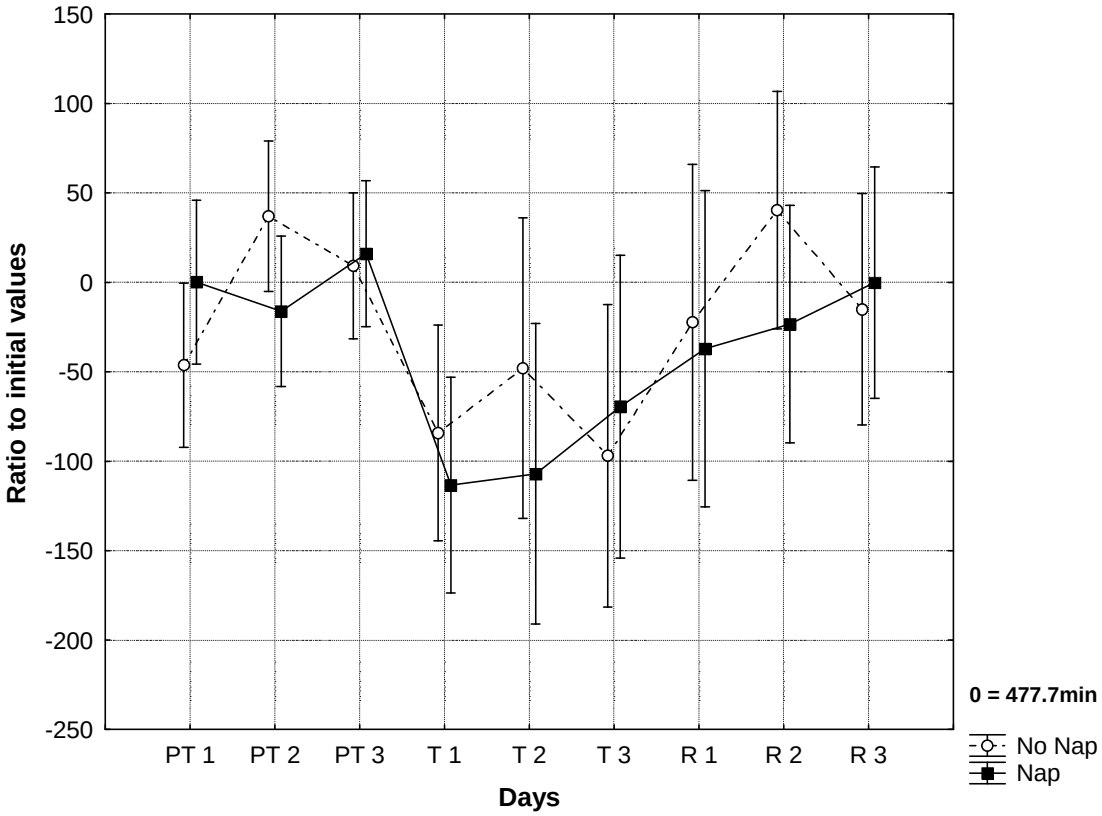

Figure 42**:** Comparison of sleep duration between both nap and no nap conditions for three days before testing, for the three days of testing and for three days after testing. All values expressed were referenced to the pre-test period values and therefore reflect a ratio to those initial values. **PT** = Pre-test period; **T** = Testing period; **R** = Recovery period.

Table XXXIV**:** Statistical effects for sleep length before, during and after testing

	SS	Degrees of Freedom	MS	F	p
Condition	10309	1, 22	10309	0.504	0.485
Days	366413	8, 198	45802	4.045	0.000 *
Days*condition	77470	8, 198	9683.8	0.855	0.556

The nap condition (first two days of testing mean = 367.53 minutes ±122.5) caused a reduced sleep length during the first two days of testing when compared to the no nap condition (first two days of testing mean = 420.85 minutes ± 120.7). Although the recovery sleep for the nap condition subjects was shorter than the no nap group, if one includes the one hour nap taken during the night time into the total recovery

sleep, there were minimal differences between the conditions. This is demonstrated in Table XXXV.

Table XXXV**:** Mean and standard deviations of the recovery sleep duration (minutes) for both the nap (NAP COND) and no nap conditions (NO NAP COND) with the shift nap (SN) included. The grey fields demonstrate the statistically significant difference between the recovery sleep for both conditions during the testing period (T), and the recovery sleep before and after testing. **PT** = Pre-test period; **T** = Testing period; **R** = Recovery period.

DAYS	NAP COND + Shift Nap (Min)	NAP COND (Min)	NO NAP COND (Min)
PT 1		477.85 (±84.1)	440.63 (±121.5)
PT 2		461.5 (±93.7)	523.9 (±106.8)
PT 3		493.8 (±85.1)	496.2 (±101.5)
T 1	424.4	364.4 (±111.4)	402.7 (±107.3)
T 2	430.65	370.65 (±133.6)	438.95 (±134.1)
T 3	468.25	408.25 (±186.6)	389.95 (±105.8)
R 1		440.65 (±154.4)	464.6 (±147.5)
R 2		454.35 (±99.7)	527.3 (±131.2)
R 3		477.55 (±112.9)	471.9 (±89.4)

Perceived sleep disturbance responses

For the napping group the number of sleep disturbances increased over the three testing days (1.6 sleep disturbances ±1.4) when compared to the figures for the pre-test and recovery phases (Figure 43). The no nap group experienced fewer sleep disturbances over the test and recovery period (1.2 sleep disturbances ±1.2 and 0.6 sleep disturbances ±0.9 respectively) than the nap group (1.6 sleep disturbances ±1.4 and 1.2 sleep disturbances ±1.3). However, the differences were not found to be significant (Table XXXVI).

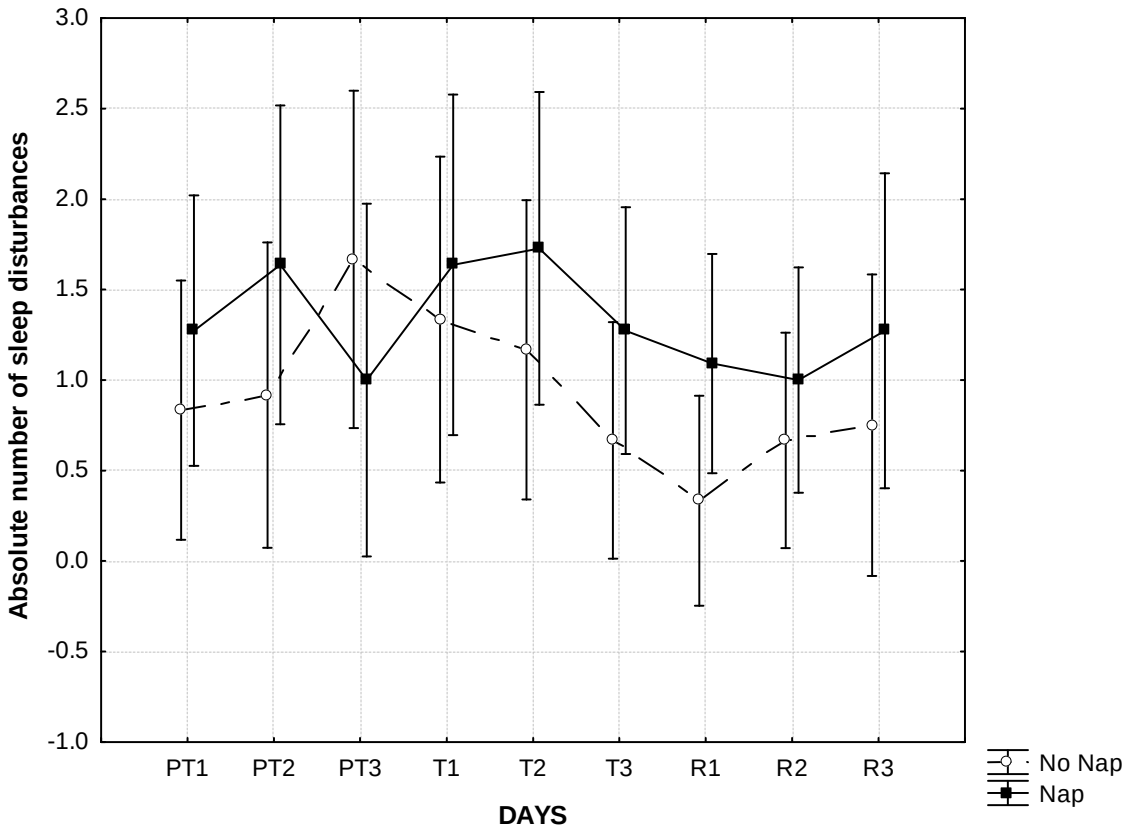

Figure 43**:** Sleep disturbances reported for the three days before, the three days during and the three days after testing for both conditions. (**PT** = Pre test period; **T** = Testing period; **R** = Recovery period)

Table XXXVI**:** Statistical effects for sleep disturbance occurrence before, during and after the testing phase.

	SS	Degrees of Freedom	MS	F	p
Condition	1.852	1, 22	1.852	0.846	0.368
Days	13.648	8, 198	1.706	1.517	0.154
Days*Condition	9.259	8, 198	1.157	1.029	0.416

Perceived sleep quality

Overall there were no significant differences in perceived sleep quality. However, during the testing period, as illustrated in Figure 44, the nap group experienced a decrease in perceived sleep quality during the data collection, whereas the no nap group experienced an increased sleep quality. The differences were not significant (Table XXXVII).

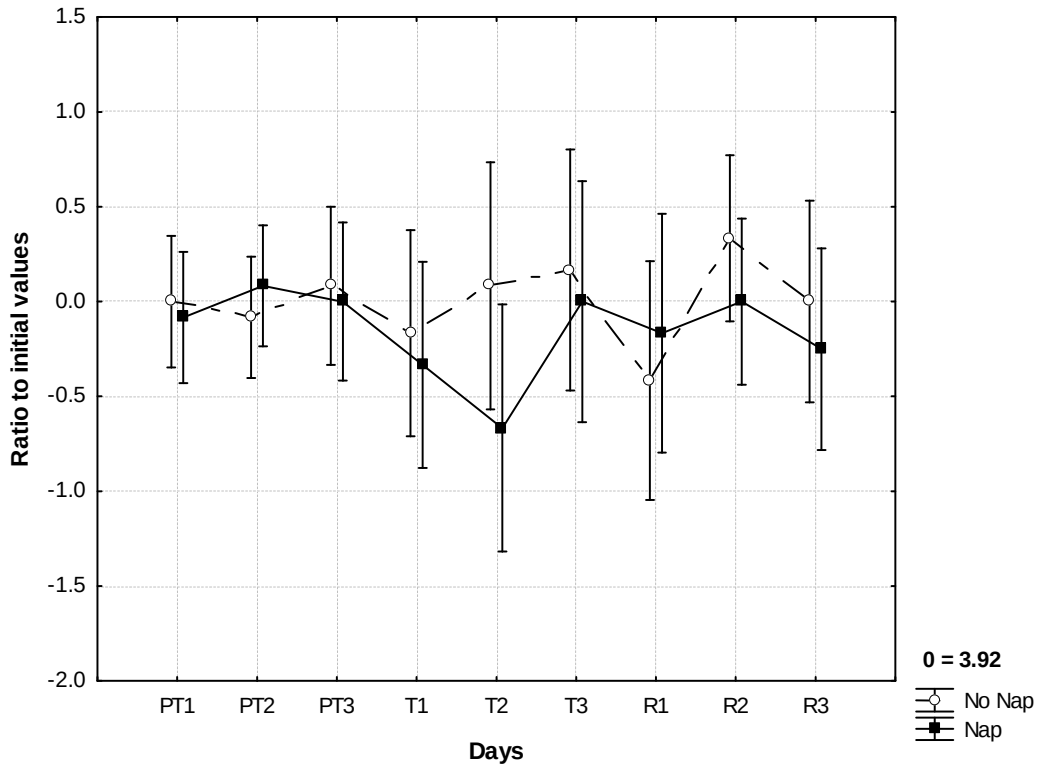

Figure 44: Perceived sleep quality reported for the three days before, the three days during and the three days after testing for both conditions. All values expressed were referenced to the pre-test period values and therefore reflect a ratio to those initial values. **PT** = Pre test period; **T** = Testing period; **R** = Recovery period.

Table XXXVII: Statistical effects for sleep quality before, during and after the testing.

	SS	Degrees of Freedom	MS	F	p
Condition	1.338	1, 22	1.338	1.091	0.308
DAYS	5.537	8, 198	0.692	1.017	0.425
DAYS*Condition	4.037	8, 198	0.505	0.742	0.655

CHAPTER V

DISCUSSION

The current research project sought to explore the effects of a flexible napping opportunity on certain physiological, subjective, neurophysiological and performance responses during simulated night shift conditions. The inclusion of a battery of tests, consisting of a range of performance and perceptual indicators, aided the researchers in gaining insight into the effects of the proposed napping intervention, when compared to no napping. These measures provided additional information on the impact of circadian and homeostatic sleep factors, while identifying any habituation effects experienced by the subjects to the three days of night work. Further insights into the interaction of the aforementioned factors and the influences of chronotype, were also gained and will subsequently be discussed.

SUMMARY OF RESULTS

Following detailed analyses of the data collected, a number of significant effects were obtained. Table XXXVIII provides an overview of these effects: many variables included in the test battery displayed circadian and habituation-related effects, with very few of these variables responding to the inclusion of the nap. Although these results are not central to the research question, they are still important for consideration. However, the variables that did respond to the provision of the nap are illustrated in the following table. Thereafter, the effects displayed in Table XXXVIII will be discussed in greater detail.

Table XXXVIII**:** Summary of all effects for all measures (For explanation of effects, please refer to the “Key considerations for statistical interpretation” section, p. 69). All “x” indicate statistical significance.

BP = Beading performance; **T TEMP** =Tympanic temperature; **S TEMP =** Skin temperature; **HRF** = Heart rate frequency; **HRV** = Heart rate variability; **HF** = High frequency component of HRV; **LF** = Low frequency component of HRV; **LF/HF** = Low frequency / High frequency ratio; **HP RT** = High precision response time; **LP RT** = Low precision response time; **HPTD** = High precision target deviation; **LP TD** = Low precision target deviation; **SRT** = Simple reaction time; **SWR** = Simple word recall test; **SL HP** = Saccade latency for High precision; **SL LP** = Saccade latency for Low precision; **CFFF** = Critical flicker fusion frequency; **KSS** = Karolinska Sleepiness scale; **WSS** = Wits Sleepiness scale.

	CONDITION	DAY	TIME	DAYS* COND	TIME*COND	DAYS*TIME	DAYS*TIME*COND	COND*CHRONO	FINAL	FATIGUE	RECOVERY
BP	x	x	x	x	x	x					
TTEMP		x	x			x				x	x
STEMP		x	x			x					
HRF	x		x								
HRV			x								
HF		x	x			x					
LF		x	x								
LF/HF			x								
HPRT			x	x							
HPTD											
LPRT	x		x							x	
LPTD											
SRT			x	x			x	x	x		
SWR									x		
CFFF											
SLHP							x				
SLLP											
KSS	x		x		x					x	x
WSS	x		x		x				x	x	x

CONDITION EFFECTS

Beading performance

Beading performance was consistently higher amongst the nap group, when compared to the no nap group over the three, separate night shifts (Figure 5, p. 72). This difference can be explained with reference to Hockey's state regulation model of compensatory control as a theoretically underpinning (Hockey, 2000). According to the model, task performance provides an indirect indication of how an individual's mental processes cope with the task requirements, as well as the environmental or contextual demands. Circadian upsets place increased strain in addition to the task demands while working at night. As a result, performance may be affected in one of two ways: in the case of the no nap group, beading performance consistently decreased throughout each of the three night shifts, which was indicative of either this group's attempt to reduce the extent of the strain induced by the task and the environment or alternatively, this decrease may reflect the effect of the natural circadian fluctuation in physiological arousal and alertness, resulting in the reduced performance.

In the case of the nap group, performance was maintained and improved throughout each night shift. This indicates that the inclusion of the nap potentially aided in alleviating the strain experienced, firstly by the unnatural work hours and secondly by the task demands. This recovery period and the associated increase in alertness would have therefore facilitated the recouping of "resources" that could be allocated to the improvement of beading performance. It is also important to take cognisance of the fact that the extent to which different individual's performance changes is task dependent (Hockey, 2000), and although beading was not a physically taxing task, it was monotonous and repetitive, requiring sustained perceptual motor control and concentration.

The actual pace at which beading performance occurred, was not controlled and subjects in different groups may have adopted their own techniques. However, all subjects sat in the same room and were exposed to every other subject's technique of beading, with the nap group still consistently producing more beads per hour than

the no nap group. Therefore, in addition to improvements in alertness from napping, concomitant improvements in concentration and attention may have translated into an increased performance.

Heart rate frequency (HRF)

Heart rate frequency responses for the nap group differed significantly to the no nap group: consistently throughout the intervals during which heart rates were measured, the nap group's HRF was higher than the no nap group's.

Despite the ease with which heart rate can be measured, the interpretation of the data is problematic, owing to the variety of factors that impact heart rate. In this case, the significantly elevated heart rate within the nap group may have been the result of the reduced fatigue effect (specifically that observed for tympanic temperature) observed in this group: heart rate is known to be affected by the time of day (circadian effects) and specifically fluctuations in body temperature. In the case of the nap group, the extent to which the tympanic temperature measures decreased throughout the night was significantly less than that of the no nap group. In cognisance of this and the established relationship between heart rate and temperature, higher heart rates in the nap group resulted from this reduced "fatigue" effect.

In addition to this, the inclusion of the nap resulted in an increase in heart rate between the Test 4 measures and the End-of-shift tests, when compared to the no nap group, which demonstrates that the nap group were operating on a higher activity level than the no nap group.

Low precision response time

A general nap effect was found during low precision response time performance, with response times being significantly faster for the nap group than the no nap group over the three night shifts. Response time refers to the summation of reaction time and movement time (Schmidt, 1988): this test requires the generation of a motor program for each target as it changes position and owing to the constantly changing target position, more visual feedback control is also required. This means

that both tests will take longer to complete than the simple reaction time test. In the context of shift work and sleep deprivation studies, reaction time has been used extensively as a sensitive measure of the effects of sleep loss and circadian upsets. Within the current study, referring to Figure 20 (p. 94), the inclusion of the nap may have reduced the extent of cognitive slowing by reducing the increasing sleep propensity and the extent of the circadian upset, which in turn produced faster response times, when compared to the no nap group.

Numerous studies (Gillberg, 1984; Sallinen et al., 1998; Purnell et al., 2002; Takeyama et al., 2004) have reported improvements in reaction times following the inclusion of scheduled naps during the early hours of the morning. Considering that it is the reaction time component that is negatively affected by sleep loss, it can be tentatively concluded that the improvements in response time within the nap group were a product of improvements in the reaction time component of response time overall. However, this is not to say that movement time is not also affected by sleep loss and circadian disruptions, as these two components are difficult to separate. Lavie et al., (1986) assessed the relationship between performance efficiency and sleepiness and on assessing movement time as part of a choice reaction time test, found that both measures displayed a circadian rhythm. Furthermore, it was established that the individuals that were required to resist sleep, produced slower reaction times and more inconsistent movement times. This further supports the claim that the nap reduced the extent of cognitive slowing, by supporting the innate biological rhythms and lessening the accumulation of sleep pressure.

Further analyses revealed that the nap condition did not differ significantly from the responses observed during the day shift: with reference to Figure 22 (p. 97) peak performance during the day shift occurred at the end of the shift which coincided with the acrophase of the circadian rhythm. Similarly, the nap condition's fastest response times also occurred at the end of the shift, which indicates the alerting effect of the nap earlier in the shift, when compared to the no nap, the responses of which were significantly different from both the day and nap conditions.

With regard to the high precision response time performance during the modified Fitts' test (Figure 19, p. 92) napping did not significantly improve response times

when compared to no napping. This can be explained by referring to Fitts' law, which states that high precision demands require longer time for the target to be reached than in low precision task performance due to higher performance demands (Schmidt and Lee, 2005). As such, the difficulty in the execution of this task may have negated any condition-related differences.

Subjective sleepiness

Napping also had a significant effect on subjective sleepiness, as measured by the Karolinska Sleepiness scale (KSS): sleepiness ratings were consistently lower during each of the three shifts for the nap group, when compared to the no nap group (Figure 30, p. 107). This finding was consistent with the studies of Saito and Sasaki (1996), Matsumoto and Harada (1994) and Smith-Coggins et al., (2006) who found KSS responses to be reduced following the inclusion of scheduled napping during the early hours of the morning. Gillberg (1984) and Dinges et al., (1987) reported no such improvements following the inclusion of naps, but this was reportedly due to the inconsistencies with regard to methodological considerations and the scales that were used (Sallinen et al., 1998). As with low precision response time, further analyses revealed that there were no significant differences in sleepiness responses between the nap and day conditions (Figure 32, p. 110). This further illustrates the benefit the inclusion of a flexible nap during the latter half of the shift in decreasing the extent of subjective sleepiness. A significant difference did exist between the no nap and the two other conditions, which again demonstrates the benefits of the nap provision.

The Wits Sleepiness scale ratings followed much the same trend in that sleepiness was significantly lower throughout the three night shifts when compared to the no nap group (Figure 33, p. 112). Consistent with the reports of haul truck operators from a selected group of platinum mines in South Africa, sleepiness ratings in the no nap group in this research were highest between the hours of 04h00 and 06h00 (Test 4 and the End of shift test) which coincided with the circadian nadir. Sleepiness ratings in the nap group during the first two shifts were also revealed to be lower than both the no nap and day conditions: this may be explained by the fact that the day subjects may have confused feelings of boredom and monotony with sleepiness.

However, even in light of this, there were no significant differences between sleepiness ratings for the nap group and the day group, but both conditions displayed significantly reduced sleepiness values when compared to the no nap condition.

The higher sleepiness ratings amongst the no nap group can be explained by the fact that sleepiness results from imbalances created by the alterations in sleep and wake cycles which would result from activities such as night shift work. Sleepiness ratings are also affected by prior sleep duration, and implicit in that, the sleep quality before the shift (Jewett et al., 1999). As illustrated in Figure 42 (p. 129) Figure 44 (p. 132) total recovery sleep duration and perceived sleep quality between the shifts did not significantly differ between the two conditions. Therefore the conclusion that can be drawn from this is that napping during the shift evoked an effect and reduced the extent of the sleepiness experienced in that group.

Furthermore, the fact that the subjects had the choice as to what time they went to nap could further explain the reduced sleepiness levels: Bonnefond et al., (2001) introduced a flexible one hour nap in an industrial plant to assess the possible long term effects on worker well being and tolerance to shift work. In their study, the empowerment of the workers in terms of controlling their work scheduling and napping, led to positive feelings, particularly with regard to job satisfaction, and the inclusion of the new scheme was widely accepted. Despite the fact that Bonnefond et al., (2001) did not assess subjective sleepiness per se and that the research was conducted over one year, similarities can be drawn to the current project: subjective sleepiness may have decreased in the nap group as subjects had control over their own work scheduling and they were free to nap when they felt the need to. This potentially may have resulted in superior sleep quality during the naps and therefore, a much greater recovery effect would have resulted, culminating in improvements in the perceptions of their state of well being. This recovery would be achieved through the alleviation of built-up homeostatic sleep pressure (as a product of time spent awake) and chronobiological sleep pressure (as a product of the natural circadian-related oscillations). This would in turn have decreased the effects of these physiological phenomena on the nap group's alertness levels and their subjective

sleepiness perceptions thereafter. The higher heart rate frequency and reduced decrease in tympanic temperature could also explain the reduction in subjective sleepiness ratings, considering the link between these physiological processes and general arousal.

FINAL EFFECTS

In most measurements, the inclusion of the nap condition failed to induce an overall condition effect. In some instances however, the nap condition produced significant effects at the end of the three-day shift cycle, when compared to the no nap condition. The scores for the simple word recall test were found to be significantly better for the nap group during the third night shift only when compared to the no nap group (Figure 26, p. 101). This finding contradicts the results of Smith-Coggins et al., (2006) who investigated the effects of a 40-minute nap opportunity on memory performance for emergency physicians: they found that napping resulted in fewer correct answers when compared to the individuals that stayed awake.

It has been established that short term memory is affected by total and partial sleep loss, which results in sleepiness and consequent reductions in alertness (Rogers et al., 2003). Working memory also depicts a circadian rhythmicity, which in turn links changes in memory-related performances to fluctuations in body temperature (Monk et al., 1997). Memory did not display a distinct circadian effect in this study, but the reduction in memory performance in the no nap group could be the consequence of increased sleepiness and therefore reduced alertness which coincided with the lowest temperatures at the circadian nadir. In their study, Williams et al., (1959) account for a similar a deterioration in memory using the lapse hypothesis: sleep loss and circadian upset result in an increase of the frequency of involuntary periods of lowered reactive capacity (lapses), which could have led to losses in attention when individuals were presented with the items to memorize. The nap inclusion may have therefore lessened the sleep loss effects, increasing alertness and the attention levels of the subjects, which improved memory performance during the third night shift.

Simple reaction time (SRT) also displayed a final effect. Unlike the high and low precision response time tests, SRT measures evoke a preset motor program that is released following the presentation of the stimulus, with little movement time required as well. It therefore requires less visual feedback control than the response time tasks and task execution is more rapid. Due to fact that the effects of the nap on SRT only became manifest during the third shift, it assumed that the effects of the nap on the circadian rhythmicity of reaction time, accumulated over the course of the first two nights. This can be explained by referring to the three-way interaction effect of day by condition by time. The extent of habituation to the irregular work hours experienced by the nap group differed significantly to that of the no nap group: the nap group evoked poorer reaction times during the first night which may have been due to the residual effects of the nap (sleep inertia) which occurred between Test 2 (00h15 to 01h00) and 4 (04h15 to 05h00). This may have been accentuated on the first day by the fact that the sample from which the nap condition subjects (and all other conditions) were drawn, had no prior experience in shift work and its irregular hours of wakefulness. Moreover, with these subjects having been asked not to sleep during the day preceding the start of their first night shift, the built up sleep pressure, accompanied by the time of day effect may have resulted in a deeper nap on the first night.

During the subsequent nights however, the nap condition responded in an opposing way to the no nap condition, with reaction time responses improving, culminating in significantly faster responses at the end of the third night shift, as illustrated by the final effect. This may be explained by the nap's role in supporting the circadian rhythm, while diminishing the natural build up of sleep pressure that is known to have a detrimental effect on reaction time during night work and periods of sleep loss. Once again, the accumulation of sleep debt and the resulting sleepiness within the no nap group may have resulted in a decrease in alertness generally. This may not have been obvious during earlier tests (Pre, Test 1 and 2), but the effects manifested during the latter tests, with the worst reaction times being evinced during Test 4 and the end of shift test on the third night shift.

In addition to this potential habituation effect, the fact that the nap group's perceived quality and perceived length of their naps was poorer and shorter respectively during the third night may be of significance: the lack of sleep on the third night would have meant that little or no sleep inertia (SI) would have been present. This is in cognisance of the fact that the intensity and duration of SI is directly linked to the length and depth of the nap (Bruck and Pisani, 1999). A lack of SI on the last night may account for the improvements in the simple reaction time for the nap group, when compared to the no nap group. In line with this point, Rogers et al. (2003) added that the time taken to recover from sleep inertia and its effects is not the same for all neurobehavioural tasks: gross motor tasks such simple reaction time are not as profoundly affected as other, more complex tasks such as mental arithmetic.

A chronotype and condition effect was also found during the simple reaction time test (Figure 18, p. 91). The inclusion of the nap had little or no impact on the mean reaction time responses of both intermediate and moderate morning types. However, the inclusion of the nap for the moderate evening type resulted in the slowing of reaction time. Conversely, among the no nap group, the moderate evening types performed significantly better. In line with this finding, Takeyama et al. (2004) concluded that napping was not as beneficial for evening types, as it was for morning types, particularly in terms of the alleviation sleepiness and improvement of early morning performance. A possible interpretation for this difference in the moderate evening and morning types and their responses to the naps, could be the length of each chronotypes circadian rhythm (Takeyama et al., 2004), specifically the point at which core temperature is at its lowest. Morning types tend to reach this point earlier than evening types and as illustrated in Figure 18 (p. 91) the nap seemed to stabilise reaction time performance in both the moderate morning and intermediate types.

The moderate evening and pure evening types tend to reach their lowest temperature later and in this study, the introduction of the nap may have occurred prior to this point, resulting in a reduced sleep quality. This claim is supported by Dinges et al., (1986) who hypothesised that nap sleep efficiency is determined by the nap's proximity to the circadian trough in temperature. These individuals would then have had to come out of the nap and attempt to perform having not slept adequately,

and then stay awake at the lowest point of their circadian rhythm, a period flagged as being the point of lowest arousal and alertness. This could explain why the nap had such a deleterious effect on the moderate evening types, compared to when those that did not nap.

Overall, the nap condition had a positive impact on the following performance and response measures, relative to the no nap condition: beading performance, which was the only true performance indicator, was enhanced by the inclusion of the nap over all three night shifts, with the group cumulatively producing more and more beads each shift. In addition to this, heart rate frequency was significantly and consistently higher for the nap group throughout the testing, which may have been the result of the circadian rhythm being supported and advanced following nap completion.

The higher heart rates, which may be used as an indicator for a higher degree of physiological arousal, as a product of the nap inclusion, also resulted in faster low precision response times consistently over the three night shifts. In addition to this, the nap response times did not differ significantly from that of the day shift, and neither did the subjective sleepiness measures: the alleviation of built up sleep and chronobiological pressure through napping, as well as the potentially higher level of physiological arousal (as discussed above) may also have reduced the subjective complaints of sleepiness in both scales, when compared to the no nap group during all three shifts. Lastly, the nap effected a reduction in simple reaction time and an improvement in memory performance during the third night shift only, illustrating the cumulative benefits of this countermeasure on improving performance during unnatural hours of wakefulness.

TIME EFFECTS

The impact of the natural physiological oscillations of the circadian rhythm in the context of shift work and sleep deprivation-related research, cannot be ignored. The circadian fluctuations, in conjunction with the homeostatic sleep process, govern the levels of physiological arousal and alertness. This in turn affects the level of performance proficiency. In the instance of these processes being disrupted by the

introduction of night shift work, the added strain associated with the maintenance of wakefulness as well as the demands of the task, places the worker at an increased level of risk. It is therefore important to understand the impact that these innate biological processes may have on the fundamental motoric, subjective and neurophysiological measures (as assessed in this research), independent of condition, ensuring that any potential problems can be managed successfully.

Temperature measures

Both tympanic and skin temperature responses decreased continuously throughout all of the night shifts, as illustrated in Figure 7 (p. 75) and Figure 9 (p.78). The lowest point in both temperature profiles coincided with the circadian nadir or the circadian "tau", which fell between Test 4 and the Post test (04h00 and 06h00). This time has been identified as a period during which accidents are most likely to occur at night, as this reduction in body temperature is accompanied by a decrease in alertness and physiological arousal (Van Dongen and Dinges, 2003; Horowitz et al., 2002).

Nathaniel Kleitman (1963) established the first systematic link between fluctuations in body temperature and cognitive performance: he found that when body temperature was at its lowest, there was a corresponding decrease in the performance of cognitive tasks such as reaction time, multiplication speed and others (Blatter and Cajochen, 2007). He concluded that the relationship was temporally causal. This postulation will underpin the proceeding discussion on why certain measures in this research displayed a circadian effect, but it does not exclude the impact of other external and internal factors. Both high and low precision response times and simple reaction time expressed a circadian effect (time effect): all responses increased over the course of the night shifts. The worst response and reaction times occurred at Test 4 (04h15 to 05h00), which was assumed to be the (average) lowest point in the circadian rhythms of the subjects in this study, as illustrated by the simultaneous lowest skin and tympanic temperature recordings.

Heart rate measures

All heart rate measures assessed in this research expressed a significant time effect over the course of the night shifts. Heart rate frequency, as discussed previously followed much the same trend as the temperature measurements: this was because the extent of physiological arousal is directly affected by the circadian rhythm, with the lowest heart rates being observed during the period between Test 4 and the of End of shift test (the nadir) (Figure 11, p. 80). Regarding the heart rate variability (HRV) measures, responses tended to again follow a circadian rhythm, with the lowest measure coinciding with Test 4 and the period just after. These decreases in HRV would have also been the product of the subjects concentrating harder on task performance during this period when circadian factors would have resulted in low levels of alertness (Figure 13, p. 83). The low levels of alertness and the requirements of the task would have resulted in an increased sympathetic response, which in turn would have decreased the HRV. This trend was more obvious in the no nap group than the nap group.

The individual components of HRV, the high frequency (HF) and low frequency power also displayed a definite time effect: the HF component tended to decrease from the start of the shift until Test 4 (04h15 to 05h00), at which point it began to rise again. In a study that explored the circadian profile of heart rate variability in shift workers, Freitas et al., (1997) concluded that HRV measures are independent of the night and day, and are influenced by times of wakefulness and sleep. In the current study, the HF responses tended to reduce throughout the night when they should be dominant: this was due to the fact that the subjects were awake when they were supposed to be asleep. As illustrated in Figure 14 (p. 85) HF responses then increased towards the end of the shift, which can potentially be explained by general increased sleep propensity and reduced level of physiological arousal among all the novice night shift workers. This observation tentatively supports the findings of Freitas et al., (1997), as the vagal tone tended to increase when the subjects were nearing the end of the shift at which time their levels of sleepiness would have been significantly higher than that at the start of the shift.

The LF displayed much the same trend as the HF component as it decreased over the course of the night shift and began to rise after Test 4 (Figure 15, p. 86). The low frequency / high frequency ratio did not differ between conditions, but also showed a definitive increase during the latter half of the night, from Test 2 (00h15 to 01h00) to the End of shift test (05h45 to 06h30) (Figure 16, p. 88). This was indicative of an increase in sympathetic modulation. The increase in sympathetic tone may be the result of all the subjects concentrating harder in an attempt to maintain their performance during the test battery while battling the effects of being awake at times they would normally be sleeping. This means that these responses differed from the natural circadian oscillations, which Furlan et al. (2000) also found in their study of the autonomic profiles of shift workers. It is these abnormal rises in sympathetic tone, when parasympathetic tone should predominate, that result in negative cardiac events associated with shift work.

Performance indicators

Task performance, in this case both response time and reaction time measures, were adversely affected by a drop in physiological responses and alertness associated with night work. Baulk et al. (2009) found reaction times to be significantly faster during the day than the night, with measures significantly increasing throughout the course of the night. Additional research conducted by Sallinen et al. (1998), Takeyama et al. (2004) Caldwell et al. (2008) also found similar results in that reaction time displayed a significant time effect, decreasing over the course of the night shift. Dinges et al. (1987) found that during a 52-hour period where subjects where devoid of sleep, all except for evenly spaced 2-hour naps, reaction time demonstrated a circadian-modulated decline.

Beading performance also displayed a significant (general) time effect: referring to Figure 5 (p. 72), beading performance tended to decrease between the first two measures for both conditions. Once again the concomitant reduction in performance can be linked to the simultaneous drop in natural, physiological arousal, as a product of the fluctuation of the circadian rhythm, as well as the lack of stimulation from the task being performed and the environment in which the task was being performed (Duffy, 1962). This conclusion is theoretically supported by the Inverted “U” principle:

performance may have been attenuated in the case of beading due to the natural circadian oscillation and accumulated sleep pressure, in conjunction with the monotony of the task. Specifically referring to the nap condition, another possible explanation for the reduced performance proficiency between Test 2 and Test 4 may be the lingering effects of sleep inertia from the nap which occurred between these two tests.

Subjective measures

Both measures of subjective sleepiness demonstrated a strong time of day effect, with sleepiness ratings significantly increasing over the course of each night shift. As with the reaction and response time performance indicators, the highest ratings of sleepiness coincided with the circadian nadir and the associated drop in tympanic and skin temperature. Referring to the KSS, during an assessment of sleepiness during long haul truck driving, Kecklund and Åkerstedt (1996) concluded that subjective sleepiness demonstrated a strong time of day effect. Sallinen et al., (1998) found similar results in their research.

Wits Sleepiness Scale ratings followed a similar trend. The research performed by Schutte and Maldonado (2003) in the South African mining industry demonstrated a clear circadian influence on WSS measures, with the highest ratings again coinciding with the circadian nadir. In both measures, as with beading performance, the different conditions affected these time effects. These will be discussed in the following section.

The irregular and unnatural hours of work and the natural fluctuation in the circadian rhythm effected changes in a number of physiological, performance and subjective measures: both temperature measures decreased throughout the course of the night shifts, with the lowest values being observed around the time of Test 4 (04h15 to 05h00). A concomitant decrease in heart rate occurred as well, which demonstrated the link between circadian-modulated temperature changes and other physiological processes in the body. The HF and LF components of HRV tended to decrease throughout the night and then increase after Test 4 (04h15 to 05h00), which was likely due to reduced levels of alertness and higher levels of concentration

respectively. HRV demonstrated a significant time effect, in that it decreased steadily throughout the night. However, this decrease resulted from an increase in the low frequency/high frequency ratio, which was indicative of greater sympathetic activity. Generally, response time measures, the simple reaction time measure and beading performance tended to mirror the natural decrease in the temperature measures and the associated reductions in physiological arousal and alertness. In addition to these changes, the accompanying accumulated sleep pressure and the reduced day time recovery sleep (see Nap effects section below) also resulted in an increase in the overall ratings of subjective sleepiness throughout the each night shift. However, in some cases, condition altered the effects of these natural fluctuations, as discussed in the following section.

TEST TIME AND CONDITIONS EFFECTS

In addition to the general condition effects, the two different experimental conditions also elicited effects on the circadian-related changes in beading performance and both subjective sleepiness measures: this refers specifically to how the two conditions differentially altered the physiological changes, as a product of the circadian rhythm during night work and how these changes resulted in improvements or decrements in variables to be discussed.

Beading performance

The nap groups' beading performance differed considerably from that of the no nap group (Figure 5, p. 72): the nap groups' performance was affected by circadian-related factors and/or residual sleep inertia effects during the first two measurements, with performance decreasing significantly between Test 2 (00h15 to 01h00) and Test 4 (04h15 to 05h00). The no nap group followed the same trend however their performance continued to decline thereafter, particularly during shifts 2 and 3, while the nap groups' performance increased. With reference once again to Hockey's state regulation model of compensatory control, these differing changes in performance result from the no nap group experiencing more strain, when compared to the nap group, which consequently resulted in a decrease in performance.

The implementation of the nap had a clear effect in reducing the strain experienced between the Test 2 and Test 4 period, evidenced in the reduced extent of temperature fluctuation and generally a higher heart rate over the course of the night. This culminated in a marked increase in beading performance during the Test 4-End of shift test period. This change in performance can be explained by the fact that the nap produced improvements in other neurobehavioural performance indicators, such as low precision response time measures (refer to condition effects section above) which may have then translated in an improved beading performance. The additional reduction in subjective sleepiness and improvements in alertness and attention may have also contributed to this heightened beading performance in the nap group, when compared to the no nap group.

However, the fact that beading performance (technique and performance criteria) was not strictly controlled, may have contributed to the group differences observed as well: some individuals may have assumed different and more effective beading techniques, which resulted in a higher beading rate per hour. In addition to this, despite their being no incentive-related motivation inherent in the beading task, some individual performed the beading task at a much higher proficiency than others, which may have reflected different personality types. This was not taken into consideration, as it was beyond the scope of this research.

Subjective sleepiness

A significant condition by time effect was also observed during the analyses of both subjective sleepiness measures (KSS and WSS). Both conditions demonstrated much the same trend in that there was a continuous increase in sleepiness levels over time, with this being the product of increased sleep pressure and the effect of the time of day. The differences between the conditions were illustrated by the extent of the increase in sleepiness: napping displayed reduced levels of sleepiness consistently over the three shifts when compared to the no nap condition. This difference can be accounted for by the nap's roe in the alleviation of the built-up sleep propensity, as well its role in supporting the natural circadian changes that occur during the night: when body temperature is low (as discussed in the time effects section above), sleep propensity is high. This will directly affect the self

perceptions of individuals with regard to their levels of sleepiness and hence the heightened levels of perceived sleepiness amongst the no nap group.

In any circadian-related research, it is important to acknowledge the masking effects of the context and the experimental conditions (Van Dongen and Dinges, 2000). For the most part, the impact of the work demands was kept constant, with no inherent motivational incentives or excessive stress associated with the task. Food intake was much the same for all subjects, with reference to the time it was provided and the size. Ambient temperatures in the laboratory were kept fairly constant and lighting, although artificial, was consistently above 500 lux throughout the night. In cognisance of this, it was therefore assumed that the differences observed with regard to subjective sleepiness were a product of the two, different experimental conditions.

In summary, referring to both beading performance and the subjective measures of sleepiness, the exclusion of napping resulted in a reduction in beads produced and an increase in sleepiness which reflected a time of day effect. Napping elicited a differential effect in that it lessened the severity of the time of day effect for both measures, which resulted in consistent improvements over the course of each night and generally over the shift cycle.

HABITUATION EFFECTS

Shift work requires workers to adopt irregular and unnatural sleeping and waking patterns, which for the most part they never fully adapt to. However, there are indicators (in this case, some physiological and performance indicators) that illustrate a certain extent of adaptation to the abnormal working regimes. In this particular study, both temperature measures displayed a significant day effect, independent of condition: tympanic temperature measurements for both conditions started at a higher level on the third night shift, when compared to the first two. In addition to this the effect of the “circadian upswing” manifested itself during the second shift, resulting in a rise in temperature out of the dead zone of the circadian nadir. This was indicative of a days and time interaction effect: the adaptation experienced by the subjects resulted in the beginning of a phase advance in tympanic temperature.

This was illustrated by the rise in tympanic temperature earlier during the second and third shifts when compared to the first shift. Although not significant, the napping condition prompted a more pronounced upswing during the second night shift than the no nap group.

As for skin temperature, much the same effect was observed: skin temperature responses during the second and third night shifts did not decrease as drastically as those observed during the first night shift. Once again, this may indicate a degree of habituation by the subjects to the atypical hours of wakefulness, which explains the interaction effect between the days and time. As with tympanic temperature, the habituation of the subjects resulted in a less pronounced drop in skin temperature as the shift cycle progressed. Both of these results are important findings. As mentioned previously, Kleitman (1963) temporally linked decrements in cognitive performance with the natural, circadian-related decrease in body temperature. In cognisance of this, and the fact that temperature has a direct impact on arousal levels and neurobehavioural responses (Rogers et al., 2003), less decreases in temperature may be associated with reduced decrements in cognitive, neurobehavioural and subjective responses. In the present study, this was evident in the nap condition's low precision response time, beading performance, subjective sleepiness ratings, memory performance and simple reaction time.

However, there were no interaction effects between condition and days for both temperature measures. Therefore one cannot conclude that the adaptation experienced by the subjects was a result of one or the other condition. In light of this, future research of this nature should observe the effects of napping versus no napping over a much longer period. This will indicate as to whether napping aids in altering the circadian rhythm of night workers, making the transition into night work easier.

Both the high (HF) and low frequency (LF) components of heart rate variability differed significantly over the course of the three-day shift cycle. Referring to both components, the responses during shift two were significantly higher than those observed during the other two shifts. This could be explained by the fact that the subjects were novices and after the first, atypical night shift and reduced day sleep

following, the levels of sleepiness may have been higher during the second night. This in turn may have resulted in elevated levels of parasympathetic activity so to promote recovery from the irregularity of wakefulness. The simultaneous increase in the sympathetic activity may have resulted from increased levels of concentration on the part of the subjects during the test battery that they were exposed to when sleepiness was high. The reduced LF responses during the third night shift may have been the product of reduced stimulation from the test battery owing to the high amount of repetition, as well as the fact that the sympathetic effects are normally subdued at night (Freitas et al., 1997). The reduced HF may have resulted purely from the fact that the subjects were awake as opposed to being asleep: when considering the LF/HF ratio, it was evident that the sympathetic component of the autonomic nervous system was more dominant during the night, as a result of the wakefulness and the need to perform during the test battery.

Beading performance for both conditions was the only other measure that was found to be significantly different over the three night shifts. The beads produced/handled during the first measurement for each separate shift (Test 1: 22h15 to 23h00), were significantly higher than the previous nights shift's. This may be explained by the lack of experience that the majority of the subjects had in beading, which resulted in an initial beading rate (Shift 1) that was slower compared to the subsequent two shifts. Thereafter, there was a very evident learning effect, which resulted in much higher performances as the subjects became more proficient in their beading techniques.

Unlike the temperature measures, beading performance displayed an interaction effect between days and condition. Beading performance was significantly higher for the nap group at the start of each shift, when compared to the no nap group. The no nap group demonstrated a reduced performance, which was probably the result of a reduction in psychomotor efficiency, which known to be affected negatively by sleep loss and circadian upsets (Rogers et al., 2003). In this study, beading performance was also self regulated and like most industrial shift work-related tasks, it was monotonous and repetitive which would have also contributed to additional reductions in alertness in conjunction with the circadian factors in the no nap group. Through the introduction of the nap however, the drop in alertness may have been

alleviated, as was evident in the simultaneous improvements in low precision response time, both of the subjective sleepiness measures (condition effects), simple reaction time performance and short term memory performance (final effect). These improvements could help to explain why the beading group produced more beads over the three shifts, when compared to the no nap group.

Effect of condition on habituation

With reference to high precision response time (Figure 19, p. 92) a significant days and condition interaction effect was found. Despite there being no general condition effect over the three shifts, the nap inclusion resulted in a change in responses: the first night saw the nap condition response times being slower than the no nap, possibly explained by the nap group still displaying the effects of sleep inertia following the nap. With reference to the nap effects section following, the subjects perceived sleep length was the longest on the first night, which may account further for the potential presence of sleep inertia. This trend changed during the subsequent two days, with the no nap group's response times being slower than those of the nap group's.

Evidently, the nap aided in the habituation of the nap group, by maintaining the performance at a fairly consistent level, while the no nap group's performance deteriorated over the course of the three night shifts. The accumulation of sleep debt in the no nap group may account for these performance decrements, when compared to the nap group. Despite the fact that all subjects were not instructed to react as precisely as possible, the difficulty of the task, compared to the low precision task, may have also been a reason for the no nap's increase in response time. An explanation for this could be that when individuals are fatigued or sleepy, they will slow down their responses to ensure that the task is completed successfully, minimising the error rate (Blatter and Cajochen, 2007).

Over all, some of the physiological measurements including tympanic and skin temperature and the high and low frequency power components of heart rate variability expressed a habituation effect to the irregular hours of work. Beading performance was the only indicator that significantly differed over the course of the

shift cycle, with this finding being the result of the subjects becoming more familiar and therefore more proficient in the technique for beading. A significant interaction effect between condition and day for both beading and high precision response time was found. This illustrated how the nap aided in the adaptation of the particular group, which resulted in marked improvement in performance over the cycle, relative to the no nap group.

FATIGUE AND RECOVERY EFFECTS (ROLLOVER)

The extent of fatigue evident in measures that depicted this effect, refers to the extent of deterioration (and in some cases, the improvement) of responses and/or performance over the course of the night (End of shift test – pre shift test). The extent of recovery refers to the difference between the End of shift-test and the pre-shift test on the next day, indicating the extent of recovery experienced during the inter-shift break. The two measures together illustrate the effect that the conditions have on the extent of performance/response fluctuation during the shift and the ensuing effect this will have on the subsequent shift's performance/response profiles.

Tympanic temperature was found to have a significant difference in "fatigue" (which refers to the extent of the temperature decrease) between the two conditions: referring to Figure 7, p. 75, the extent of the temperature change for the nap group was significantly lower than that of the no nap group over all three shifts. This may be explained by referring to the phase response curve of the circadian rhythm: conventionally, the introduction of bright light just before or after the temperature minimum causes a phase delay or advancement respectively, in the circadian rhythm (Minors et al., 1991). By the very same principle, the introduction of the nap may have resulted in a phase advancement in that, during the second night shift, the circadian upswing in temperature occurred sooner than that of the no nap group. This may be a result of the nap once again, supporting the natural circadian rhythm, alleviating sleep pressure and then, following the exposure of the workers to a well lit work environment, resulting in a minor phase advance in their circadian rhythm (Shift 2). This may help to account for the less pronounced drop in temperatures for the nap group, when compared to the no nap group. In line with Kleitman's postulation, this smaller change in temperature in the nap group may also be used to account for

the improvements in some performance indicators and subjective sleepiness measures namely: beading performance, low precision response time, simple reaction time, short term memory performance (both final effects), Karonlinksa Sleepiness and Wits Sleepiness Scale responses.

In terms of recovery, the nap group's recovery was lower than the no nap group because the nap group's temperatures did not fluctuate as much as the no nap group's temperatures did. Again, this may be attributed to the effect of the nap during the previous shift: if indeed a phase advancement was induced by the introduction of the nap during all the shifts, then the temperatures of the nap group at the end of the first and second shifts, would not differ significantly from those at the start of the following shifts (Shifts 2 and 3 respectively), when compared to the no nap.

A significant difference in fatigue was also found between the conditions during the low precision response time task. As illustrated in Figure 21 (p. 96) the nap resulted in significantly less fatigue in terms of response time slowing over the shift than that of the no nap group. The nap resulted in faster response times at the end of the shift, relative to the start of the shift. The opposite effect was found for the no nap group. This difference can be explained by referring to the abovementioned discussion: the nap group experienced less dramatic decreases in tympanic temperature than the no nap group. In light of this and the fact that there exists a temporal relationship between temperature fluctuation and cognitive and neurobehavioral performance, the reduced extent of temperature change in the nap group resulted in better response time performance throughout all the night shifts, compared to the no nap.

Finally, in the case of both sleepiness scale measures, there was a significant difference in the fatigue experienced between the conditions: the nap inclusion resulted in considerably less subjective sleepiness fluctuation over all of the night shifts, when compared to the no nap condition (Figure 31, p. 109 and Figure 34, p. 113 respectively). The reduced extent of sleepiness oscillations evinced in the nap group could have occurred for a number of reasons: as mentioned previously, the provision of the nap may have abated the ever-increasing sleep pressure, while providing some stability to the natural circadian rhythm, which culminated in reduced feelings of sleepiness by the end of the shift. Moreover, the self control afforded to

the subjects regarding nap timing may have aided in improving the recovery sleep experienced during the nap, which could have bettered the nap subject's sleepiness perceptions during the early hours of the morning (between Test 4 and the End of shift test).

The recovery effect was also less pronounced for the nap group compared to the no nap group: there was very little difference in inter-shift sleepiness due to the fact that the low end-of-shift sleepiness ratings for the nap group did not differ significantly from the pre shift measures the following day. Therefore, as with the fatigue effect, the nap aided in reducing the extent of recovery that the nap group had to experience between the shifts because this group were not as fatigued as the no nap group at the end of each shift.

In brief, napping aided in reducing the extent of on-shift "fatigue", specifically the extent to which the End of shift measures differed from the pre-shift measures. Tympanic temperature, low precision response time and both measures of subjective sleepiness were not as adversely affected by the unnatural shift work conditions amongst the nap group, when compared to the no nap group. This curtailment in the extent of response fluctuation for the nap condition was also accentuated over the course of the shift cycle. Moreover, the reduced extent of fatigue meant that the magnitude of the recovery that had to be made between the shifts was lessened, relative to no nap group: this was reflected clearly in tympanic temperature responses and in both subjective sleepiness measures. Together, these findings demonstrate the rollover effect, reflecting the difference the nap inclusion had made to the abovementioned responses and the cumulative benefits that manifested during the entire shift cycle.

UNEXPECTED RESULTS

Prior to the commencement of data collection, considerations were made so as to include a variety of measures that had previously been used in other research to study the effects of sleep deprivation and fatigue associated with shift work. One such measure was saccade latency, which forms part of broader electro oculographic measurement techniques applied in industry to assess fatigue and

sleepiness (Zils et al., 2005). In the context of this research, it was hypothesized that saccade latency would be affected negatively by the circadian disruptions associated with simulated shift work studies, resulting in an increase in saccade latency. Furthermore, it was expected that the nap would aid in the decrease of saccadic latency responses during the early hours of the morning, after nap completion.

The opposite effect was observed: with reference to Figure 28 (p. 104) and Figure 29 (p. 106) which depict the saccade latency responses during the high and low precision tasks respectively, the no nap group's responses generally decreased over the course of each night shift, particularly over the second and third shifts. The nap resulted in an opposing increase in saccadic latency over the course of shifts, with the worst responses occurring towards the end of shifts. The decrease in the no nap group's responses could be attributed to a learning effect: the index of difficulty was set a constant value for both high and low precision tests and the size of the touch screen limited the places for the targets to appear. As such, the alternation between the targets on the left and right hand sides of the screen was observed by the subjects, which resulted in this learning effect. The subjects could not accurately predict where the next target would appear, but the learning effect resulted in the subject's gaze already being on the side the target was to appear, prior to it appearing, resulting in a shortened saccadic latency (Teplitz, 1991; Robertson, 2009). This finding contradicts the results of De Gennaro et al., (2001) who found saccade latency responses to mirror the natural circadian rhythm, with responses beginning to decrease from midnight and deteriorating further until the arrival of the morning.

DIFFERENTIAL CONDITION EFFECTS

Critical considerations of lowest performance responses by condition

In order to gain more insight into the different ways in which the two conditions affected the variables assessed during this research and the associated risks that may arise with their implementation, a comparison was made between the lowest points of performance/responses for each condition.

In the identification of the lowest point of performance (slowest response times) during the low precision response time measures, it was determined that with the inclusion of the post nap data, response times were significantly worse for the nap group when compared to the no nap group (Figure 36, p. 116). As evinced in the aforementioned figure, it was evident that response time performance was not only poorer during the post nap tests for the nap condition, but performance worsened over each night. As will be discussed, this may the product of sleep inertia following the nap, which has been known to negatively impair neurobehavioural tasks such as reaction time and other psychomotor tasks (Dinges et al., 1985; Tassi and Muzet, 2000). However, in the analyses that excluded the post nap data, there were no significant differences between the lowest points in response time performance, with the nap condition's performance in some cases, being better than that of the no nap group.

Much the same trends were observed in the analyses of the simple reaction time responses (Figure 38, p. 119): the inclusion of the post nap resulted in the nap group's performance being significantly worse than the no nap, potentially as a result of sleep inertia. Excluding the post nap data produced no significant difference between the two conditions. These two results have important practical implications: if napping is implemented as a fatigue countermeasure, it is ill-advisable for a worker to return immediately to work, as the effects of sleep inertia may impact subsequent work performance and personnel safety. This is obviously dependent on nap length and timing (Matsumoto, 1981), prior wakefulness (Dinges et al., 1985; Balkin and Baida, 1988) the type of task to be completed (Tassi and Muzet, 2000) and the urgency associated with task completion.

During the low precision target deviation task, there was a significant difference between the two conditions: napping, with and without the post nap included, resulted in consistently poorer performances than the no nap group. This means that the reductions in performances were not necessarily due to the nap. This may have resulted from the fact that the nap group displayed significantly faster response times in this particular task than the no nap group. This may have meant that the no nap group, who were potentially sleepier than the nap group, would have slowed their

response time down in the attempt to be more accurate, which they were. The nap group's poorer performance may either be attributed to the presence of sleep inertia immediately after the nap (in the case of the first shift) or the residual effects of this phenomenon on later performances, which has been known to result in reductions in psychomotor and neurobehavioural performance.

Saccade latency during the low precision task, also expressed a significant difference between the conditions with the inclusion of the nap producing the slowest latencies, with the post nap included. With the exclusion of the post nap, no differences were found, but saccadic latencies for the nap group were still slower than those of the no nap group. Ferrera et al., (2000) found that saccade latency tended to increase (get slower) immediately after a nap and compared to a no nap group, and this could explain the current finding. Having outlined the reasons for why the saccade latencies observed during this research are in contradiction to established findings, the fact that the napping causes a reduction in these oculomotor responses is of concern. Although this research did not focus on any other oculomotor components, individuals who are required to perform tasks that require high oculomotor control, should be allowed a period of time after awakening to allow for the dissipation of sleep inertia.

In general, the inclusion of the flexible nap poses some concerns when considering its effects on performance during the shift, relative to the exclusion of a nap. In this case, the inclusion of the nap resulted in a significantly reduced performance/response ability, specifically immediately after the nap. The responses for low precision response time and target deviation, simple reaction time and saccade latency (during the low precision task) were found to be significantly worse immediately after the nap relative to the poorest responses for the no nap group over the course of the entire night. Not considering the post nap revealed no significant differences between the two conditions and the associated worst performances. This finding illustrates the importance of making provision for a short period of time just after the nap, during which individuals may recover from the effects of sleep inertia before resuming work.

NAP EFFECTS

Sleep during the nap

A significant difference was observed between the average perceived length of the naps over the three days: all subjects tended to sleep for longer on the first night, with the length gradually decreasing during shifts 2 and 3 (Table XXVI, p. 121). This may be as a result of one of the experimental requirements: subjects were asked to not sleep during the day preceding the start of their first shift, and this may have resulted in the accumulation of natural sleep pressure. All subjects tended to go to nap earlier on their first night shifts relative to either of the subsequent shifts and due to the flexible nature of the nap, a comparison between perceived length and quality of the sleep at different times was not possible. There were no significant differences observed with regard to perceived sleep quality either.

Nap timing and performance / response breakdown

In the attempt to establish a possible relationship between the extent of performance breakdown and the onset of napping, a correlation was made between nap timing and the performance change between the Pre-nap test (flexible) and Test 2 (fixed). The results show strong, negative correlation between tympanic temperature and nap timing but only on the first night: this means that the subjects chose to nap when their tympanic temperatures were nearing their minimum. A strong positive correlation between both high and low precision target deviation and nap timing was also established: in this case the deterioration in precision performance had an impact on when the subjects went to nap. Finally, a strong positive correlation was found between subjective sleepiness (KSS) and nap timing: again, the extent of sleepiness on the first night, resulting from the build up of sleep pressure over the course of the whole day while the subjects were awake, had an impact on when the subjects chose to nap.

These reductions in some performance indicators and the increase in subjective sleepiness can be linked to the change in body temperature, the decrease in which has been temporally linked to increased drowsiness and a higher sleep propensity. It is this relationship that aids in explaining the relationship between these variables

and nap onset. However, no similar trends were found during subsequent shifts, which may be indicative of an adaptation by the subjects to the conditions, or individual-specific strategies in when to nap.

Beading performance and napping

A correlation between the nap timings and absolute beading performance revealed a weak dependence, all except for shift 2 (Table XXIX, p. 124). It was found that the later the nap occurred, the more beads were produced by the end of the shift. This dependence can potentially be explained by the fact that the nap subjects had the choice as to when they napped and those that chose to work later may have perceived the nap as “reward” and something to work towards. In essence, without it being explicit, the subject may have been motivated by the “recovery” to come and as such, worked harder and more consistently, and this resulted in a higher number of beads being produced. Dinges et al. (1986) commented that in any nap-related research, results may potentially be contaminated by what these authors refer to as “transient motivational” factors such as the above mentioned perceptions, but in this case, the inclusion of the nap seemed to be positive in that it resulted in improvements in performance.

As demonstrated in Figure 40 (p. 124), subjects that chose to nap earlier during the shift produced less beads by the end of the shift. The residual effects of sleep inertia in addition to the repetitive and monotonous nature of the beading task could account for this: for tasks that are cognitively taxing, incentive-based or demanding in terms of performance requirements, the effects of sleep inertia may be overcome in the attempt to adequately meet these demands. There was no strict performance requirements associated with the beading task and as a result, those individuals that chose to nap earlier would have had the double burden of overcoming sleep inertia and continuing with a task that was not stimulating. An earlier nap would also have meant that individuals would have woken up well before the nadir: this fact, accompanied by the associated reductions in alertness and physiological arousal, would probably have negatively affected beading performance.

In a comparison of beading performance (beads/hour) for the two conditions, between Test 2 and Test 4, there were no condition-related differences in performance. However, during the first two shifts, napping performance was lower than that of the no nap group: this could be attributed to the fact that perceived sleep length and quality were longer and higher respectively during shifts 1 and 2. These longer and potentially better quality bouts of sleep may have resulted in some degree of sleep inertia, and hence the reduced performance between the two tests. The third shift saw an improvement in the nap condition performance relative to the no nap group: the nap taken during the third shift was the shortest and the lowest in terms of quality. Therefore, the subjects on this particular day may have not had to contend with the negative effects of sleep inertia following the nap. The gradual increase in beading output each shift by both condition groups was the product of task familiarisation.

In summary, nap length and quality tended to decrease over the course of the shift cycle, with the choice in timings also being later for each separate shift. Only changes in tympanic temperature, high and low precision target deviation responses and Karolinska Sleepiness ratings between Test 2 and the Pre-nap during the first shift correlated with nap timing. Keeping with nap timing, absolute beading performance was found to be higher in individuals who chose to nap later rather than earlier. Despite sleep inertia following the nap being of concern with regard to beading performance between Test 2 and Test 4, no significant differences were found between the two conditions over the three days, with napping actually producing more throughout this period during the final shift.

Sleep inertia effects

Table XXXIX: Summary of variables affected by Sleep inertia as determined by the comparison between pre-nap and post-nap measures over the course of the three days of testing. All **shaded "x"** refer to the presence of statistical significance. **DAYS =** refers to the significant differences between pre and post nap measures over the three days. **MEASURES =** refers to general significant differences between the two measures.

Variable key: **T TEMP** =Tympanic temperature; **S TEMP** = Skin temperature; **HP RT** = High precision response time; **LP RT** = Low precision response time; **HPTD** = High precision target deviation; **LP TD** = Low precision target deviation; **SRT** = Simple reaction time; **SWR**= Simple word recall test; **SL HP** = Saccade latency for High precision; **SL LP** = Saccade latency for Low precision; **CFFF** = Critical flicker fusion frequency; **KSS** = Karolinska Sleepiness scale; **WSS** = Wits Sleepiness scale)

	DAYS	MEASURES
TTEMP		
STEMP		
HR/HRV		
HPRT	x	x
HPTD		
LPRT		x
LPTD		
SRT		x
SWR		x
CFFF		
SLHP		
SLLP		
KSS		
WSS		x

Within the current research, insight into the structure and depth of sleep experienced during the nap was not possible. Therefore, the extent of performance or response fluctuation between Pre-post nap tests was assumed in this case to reveal the effects of sleep inertia. Referring to Table XXXI (p. 126) the summary of which is Table XXXIX (above), in all the response and reaction time variables, the post nap tests revealed consistently slower responses. Memory, as well as subjective sleepiness (as measured by the Wits Sleepiness Scale), were also affected negatively after the nap. Simple and complex reaction time responses are known to

be affected negatively by sleep inertia (Dinges et al., 1985; Tassi and Muzet, 2000). The extent of the sleep inertia experienced was found to not be strongly correlated to either perceived nap length or perceived sleep quality during the nap (Table XXXII, p. 127 and Table XXXIII, p. 128 respectively). The worsening performance observed during all the reaction and response time tasks can be explained by the fact that sleep inertia results in a lowered level of arousal, revealed by a general slowing in cognitive processing (Tassi and Muzet, 2000). This slowing in cognition would therefore result in an increase in the time taken to perceive the stimuli during the reaction and response time tests, which in turn resulted in decrements in these performances. In contradiction to the present results, Purnell et al. (2002) found that post-nap reaction time performance did not differ from that of the pre-nap following a 20 minute flexible nap between 01h00 and 03h00. This discrepancy may be explained by the fact that the presence of sleep inertia is dependent on the length and quality of sleep prior to waking: in this case, 20 minutes may have not been enough time for the subjects to have reached a deep enough state of sleep to suffer from sleep inertia affects upon waking.

Memory performance was also reduced after awakening from the nap. This is in accordance with the results of Åkerstedt and Gillberg (1979) who found that memory performance deteriorated over the course of the night following repeated awakenings, as a result of deeper sleep induced by sleep deprivation. In the present study, the reduction in alertness as a product of the nap may have resulted in an increase in the frequency of lapses, as discussed previously, which would have consequently led to increased inattention when the subjects were presented with words to memorise. This in turn may have contributed to the decrease in the correct number of words recalled. However, Tassi and Muzet (2000) argued that word memory is hardly affected by sleep inertia: their argument is that there exists a difference between hypo-arousal and hypo-vigilance, the latter of which would deal specifically with attentional processes. However, this argument remains beyond the scope of this research.

Finally, significantly higher ratings of subjective sleepiness were observed just after the nap (as measured by the Wits Sleepiness Scale). Purnell et al. (2002) found that

following the implementation of a 20-minute nap between 01h00 and 03h00, subjective sleepiness was significantly increased immediately following the nap on the first night, but not during the second night. In addition to this difference in pre and post-nap sleepiness being attributed to sleep inertia, the fact that in most cases, the subjects awoke just prior to the assumed circadian trough may have also resulted in increased sleepiness (Åkerstedt and Landström, 1998). This fact applies to all the variables discussed previously in this section: waking up near to or in the circadian nadir may accentuate the effects of sleep inertia due to the sleep just prior to waking, being deeper. The nadir is also associated with the lowest point in body temperature, which has been linked to reductions in neurobehavioural performances. However, without the ability to fully gain insight into where the lowest point in the temperature profile occurred for each subject, as well as the quality of sleep achieved during the nap, the effects of sleep inertia could not fully be investigated in this research.

A significant oversight within the current research must be acknowledged: no additional test batteries were administered at regular intervals after the nap had been completed. This meant that the time course of sleep inertia dissipation could not be monitored. Future research of this nature should consider the effects of sleep inertia and careful consideration must be made with regard to setting up an appropriate series of tests to monitor the prevalence and dissipation of sleep inertia following a night time nap.

Briefly, following the comparison of post and pre-nap measures, it was found that sleep inertia had a negative impact on high and low precision response times, simple reaction time responses, memory performance and sleepiness ratings. Considerations need to be made with regard tracking the time over which these sleep inertia effects dissipate, and the response of performance and subjective measures to this change.

SLEEP DIARY RESPONSES

Recovery sleep during the day

In addition to the negative effects of sleep inertia just after the cessation of the nap, research has also questioned the impact that night time napping has on the subsequent day (recovery) sleep (Åkerstedt et al., 1989; Takeyama et al., 2005). In the current study, both conditions experienced significant reductions in sleep length when they were forced to sleep during the day following the night shifts. Åkerstedt (1995) reported that post-shift recovery sleep tended to be reduced by two to four hours: in the current research, the napping group's recovery sleep was reduced by ±90 minutes, while the no nap group's by ±75 minutes, relative to the pretesting period sleep. This reduced sleep length is a direct result of the subjects having to sleep when they should be awake: sunlight, the most prominent *zeitgeber* makes sleeping during the day very difficult as it is associated with a rise in circadian rhythm and therefore physiological alertness (Åkerstedt and Gillberg, 1981). This rise in the circadian rhythm may be overridden by the high need for sleep, as a product of prolonged wakefulness, but if this is not the case, then day time sleep will be shortened (Åkerstedt and Gillberg, 1981). Although a reduced recovery sleep may be perceived as negative, if the length of the nap was added to the day sleep, as Matsumoto and Harada (1994) did in their study, the nap recovery sleep in most cases was longer than that of the no nap group (Table XXXV, p. 130). Takeyama et al. (2005) commented that this reduced day time sleep was in some instances, beneficial in that it provided shift workers with the opportunity to engage in other activities during the day, other than sleeping.

In addition to the length of the recovery sleep, the number of disturbances and the perceived sleep quality during the recovery period were recorded in each subject's sleep diary. Neither the nap, nor the no nap group experienced a significant increase in sleep disturbances during the day. This is in contradiction with the reports by Åkerstedt et al. (1991) who found that night shift workers experienced an increased frequency of untimely and spontaneous awakenings. The difference may be explained by the fact that the sample group consisted of novices. Therefore the unnatural and unaccustomed hours of work may have resulted in significant sleep

pressure build up which may have culminated in higher sleep quality, but not necessarily longer sleep. This was the case for the no nap group, whose perceived sleep quality was better over the three days of testing, when compared to the nap group. Despite this difference not being significant, the nap did contribute to a reduced sleep quality, which is in line with the findings of Sallinen et al. (1998) who reported a reduction in the quality of sleep (as measured by an EEG) following a 50-minute nap taken at either 01h00 or 04h00.

Finally, it was established that although day time recovery sleep was significantly shorter for both night time conditions, when compared to before and after the testing period, napping did not significantly reduce this sleep period, relative to the nap-less group. Furthermore, sleep disturbances were not significantly different between both groups over these nine days, however, the nap did reduce the perceived quality of day time sleep relative to the no nap group, but this was not significant.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Napping has been identified as a plausible and reliable fatigue and sleepiness management strategy during shift work. Despite this well established fact, the recommendations surrounding its implementation have been hampered by differences in the way it has been studied: prescribed naps of varying lengths and timings have at times yielded differing results. Generally, consensus has been reached in that, naps that take place during the latter part of the night (if a prophylactic nap was not possible) tend to improve early morning alertness and performance, relative to no napping. Yet there have been no definitive conclusions regarding nap length or timing during shift work. An additional concern amongst researchers in the field is the extent of sleep inertia that will result from waking near to or in the circadian nadir and the impact that this will have on subsequent performance.

An additional challenge to nap prescription centres around the fundamental differences between individuals, their circadian rhythms and their ability to cope with the unnatural hours that shift work may present. In cognisance of these challenges and in an attempt to circumvent them, a flexible time frame was introduced, during which individuals could chose when to nap for a short period of time, in the context of simulated night shift conditions. The objective of this study was to therefore determine the effects of this intervention, relative to no napping, on various physiological, subjective, neurophysiological and performance responses during a three-day night shift cycle.

SUMMARY OF PROCEDURES

In an attempt to assess the effects of the flexible napping intervention on a host of physiological and subjective responses, and performance indicators, simulated night shift conditions were created in a laboratory. A total of thirty-six university students

were recruited for the study, with this sample comprising of an equal number of males and females. Each subject was asked to attend two habituation sessions: the initial session dealt with the explanation of the experimental setup and procedures and the acquisition of informed consent. The second session provided an opportunity for the subjects to practice the tasks and the measures to be administered and become familiar with the laboratory conditions. Each subject was also informed as to when they were to report to the laboratory and prior to leaving, were presented with their nine-day sleep diary.

The testing spanned twelve days. Within this period there were a total of four, three-day shift cycles: three night shift cycles and one day shift cycle. Each night shift cycle was comprised of 12 subjects. This group was further divided into three separate conditions: 4 subjects made up the no nap condition, 4 subjects formed part of the nap condition and 4 subjects formed part of a booster break condition (separate, collaborative study). All the day shift subjects formed part of one control condition that followed the same structure as the no nap condition during the night shifts. Each subject was randomly assigned to a particular shift cycle based on their chronotype and sex, ensuring that there was an equal distribution of both in each cycle. Subjects reported to the laboratory at 21h00. The night shift commenced at 22h00 and ended at 06h00. Regarding the day shift, subjects arrived at the laboratory at 07h00, with the shifts beginning at 08h00 and ending at 16h00.

The no nap condition was structured as follows: the subjects were afforded three evenly-spaced rest breaks throughout the night (as found in most work environments), the total time of which amounted to one hour. These subjects were not permitted to nap, but took their breaks in a separate room to the testing and working areas. The nap group were afforded the opportunity to nap for one hour between 00h00 and 03h00 (if subjects slept at 03h00, they were awoken at 04h00). The day shift followed much the same structure as the no nap group.

Throughout all shifts, there were a total of six scheduled and relatively evenly spaced testing batteries. The pre-shift test occurred prior to the start of the shift (between 21h00 and 22h00). After the pre-shift test, all subjects were exposed to four shift tests that occurred two hours apart. At the end of the shift and prior to the subjects

being released, they were exposed to an end of shift test. The test battery comprised of the following dependent variables:

Physiological responses:

- Tympanic temperature
- Skin temperature
- Heart rate frequency
- Heart rate variability
- High frequency power
- Low frequency power
- Low frequency/high frequency ratio

Performance indicators:

- Beading performance
- Low and high precision response time
- Low and high precision target deviation
- Simple reaction time
- Simple word recall (memory) test responses

Neurophysiological measures:

- Saccade latency (high and low precision)
- Critical flicker fusion frequency

Subjective measures:

- Karolinska Sleepiness Scale
- Wits Sleepiness Scale

Prior to the commencement of the nap, each subject was exposed to a pre-nap test battery. Subjects were provided with dormitory-type sleeping quarters, with males and females being separated. The rooms were sufficiently dark and quiet and removed from the working area. After one hour, each subject was awakened and within five minutes, exposed to a post-nap test battery before returning to work.

While the subjects were not being tested, they were required to perform two tasks: the primary task was a very simple beading task while the secondary task involved packing information brochures into envelopes. The tasks were repetitive and monotonous, but they permanently required perceptual motor control and attention. Subjects sat together in the same room and were permitted to interact while being monitored by a research assistant. Food in the form of a limited selection of sandwiches was provided two hours after the shift had begun, at the midpoint of the shift and two hours prior to the end. This coincided with the scheduled breaks for the no nap condition, the subjects of which left the working area to eat while the nap group ate their food at the work stations.

At the end of each shift the subjects were encouraged to sleep for no less than 5.5 hours and they were asked to consistently record a sleep diary, considering their sleep and waking times, the length of the recovery sleep, its quality and the number of disturbances experienced.

SUMMARY OF RESULTS

The inclusion of the nap had a positive effect on a number of variables over the course of the entire night shift schedule: beading performance was significantly higher in the napping group than both the no nap group and day group. In a comparison of beading performances for both night shift conditions, it was found that nap group's beading rate was not adversely affected during the period in which the nap occurred (and sleep inertia may have been present) when compared to the no nap group. Furthermore, napping resulted in significantly faster response times during the low precision modified Fitts task as well as higher heart rate frequency recordings, relative to the nap-less condition. With respect to both measures of subjective sleepiness, napping consistently reduced sleepiness ratings. With reference to just the third night shift, simple reaction times were faster and memory performance was improved as a result of the nap, indicating a significant final effect of the nap intervention. In terms of the low precision response time responses and the two sleepiness measures for the nap, comparison to the day shift responses yielded no significant differences.

Regarding the rollover effects, napping significantly reduced the extent of fatigue observed in tympanic temperature and low precision response time responses and both measures of subjective sleepiness responses over the three-day night shift cycle. Napping also resulted in significant recovery effects for all the above mentioned factors, excluding low precision response time. Together, these two effects illustrate the roll-over effect of the nap, specifically how its inclusion during one shift, had an impact on the performance or responses during the next shift.

In addition to the immediate condition effects, the nap condition also had an impact on the ways in which circadian-related fluctuations in performance indicators and responses changed. With reference to beading performance, the introduction of the nap resulted in improvements in alertness and reduced sleepiness which in turn resulted in higher beading performances in the nap group, relative to the no nap. The nap also resulted in reductions in subjective sleepiness ratings during all three days of testing, when compared to the no nap group, whose sleepiness ratings were consistently higher during this period. The two different conditions also had an influence on the extent of adaptation experienced by the subjects to the night shift conditions. This was evident in the beading performance, where napping positively aided in the adaptation of subjects to the night work. Simple reaction time and high precision response times improved as a result of napping, with this change being evident over the three night shifts.

For both simple reaction time and saccade latency during high precision modified Fitts task, napping aided in habituating the subjects with this habituation subsequently altering the responses of the above mentioned variables to the circadian-related factors. This means that napping gradually lessened the slowing effect of the circadian rhythm on these two measures, resulting in a decrease in simple reaction time and saccade latency responses over the three days of testing. Simple reaction time improved significantly over the three days for the nap group while saccade latency increased for the same group. With regard to simple reaction time, an interaction effect between chronotype and condition was found. This meant that the effect of the nap was dependent on the chronotype to which the intervention was applied. In this case, napping tended to stabilise the performance of moderate

morning and intermediate types, and worsen all moderate evening type's simple reaction time responses.

As for the comparison of the poorest performance or responses for both conditions over the course of the shift cycle, it was deduced that for responses during the low precision task (response time and target deviation), the simple reaction time test and saccade latency responses during the low precision task, the nap condition produced worse responses/performances relative to the no nap condition. This was due to the inclusion of post nap data which reflected the effects of sleep inertia on the above mentioned variables. Without considering this data, there were no significant differences between the nap and no nap for these variables except for the target deviation responses.

Nap effects

The perceived length of the nap differed significantly over the three night shifts, getting shorter each night. However, there were no significant differences in perceived nap sleep quality or the timings at which the nap took place over the three days. Comparisons between pre-nap and post-nap responses revealed that high and low precision response times, simple reaction time, memory performance and subjective sleepiness ratings were negatively affected by sleep inertia after the nap. Additionally, pre-nap and post-nap response fluctuations did not correlate with either perceived nap sleep length or quality. Nap timing positively correlated with beading performance, indicating that subjects that napped later tended to produce more beads by the end of the shift.

The day time recovery sleep for the nap group did not differ significantly from that of the no nap group. However, the general sleep length for both conditions was significantly lower when compared to the three days before and the three days after the shift cycle. The number of sleep disturbances did not differ by condition but perceived sleep quality during the day was lower for the nap group compared to the no nap group.

Circadian effects

A number of measures in the current study expressed circadian-related changes over the course of each shift, which was indicative of reduced physiological arousal and alertness. From a physiological perspective, both skin and tympanic temperature decrease over each night shift as did all of the heart rate measures. With respect to the performance indicators, high and low precision response time and simple reaction time mirrored the trend in temperature reduction throughout each night shift. Lastly, both measures of subjective sleepiness also expressed a significant time effect consistently over the three-night shift cycle.

Habituation effects

Beading performance and both temperature measures expressed a significant habituation effect in that, the responses for these measures changed for each shift: beading performance increased due to task familiarisation while temperatures started higher and did not decrease as much over the course of the three shifts. Both the low and high frequency power of heart rate variability also differed over the three days.

Other results

No significant effects were found regarding the ascending threshold of critical flicker fusion frequency. The saccade latency responses were unexpected: saccade latency responses during both the low and high precision tasks decreased amongst the no nap group and increased for the nap group.

HYPOTHESES

The research hypothesis proposed that napping, when compared to no napping, would result in improvements in performance and response variables during the course the three-night shift cycle. In addition to this, it was further proposed that napping would have an effect on the habituation of the subjects to the unnatural conditions and potentially exert an effect on the circadian-related changes in all responses, relative to the no nap group.

Hypothesis 1:

The study tested the hypothesis which proposed that napping would not evoke a general change in the performance and response variables over the course of three night shifts.

a) H_o: µPARA(General condition level)$_{nap}$ = µPARA(General condition level)$_{no\ nap}$

The nap condition had a general positive effect on beading performance, heart rate frequency, low precision response time and both subjective sleepiness measures throughout the entire night shift cycle. Therefore, the null hypothesis is rejected for these particular variables and the alternative hypothesis is tentatively accepted.

b) H_o: µPARA(Final condition level)$_{nap}$ = µPARA(Final condition level)$_{no\ nap}$

With regard to the final effects, napping resulted in improvements in beading performance, simple reaction time responses, memory performance and subjective sleepiness (Wits Sleepiness Scale) during the third and final night shift. The null hypothesis is therefore rejected for these variables, as the changes observed in these responses were dependent on napping.

With respect to the general roll-over effects, napping significantly reduced the extent of both fatigue and recovery in the tympanic temperature measures and both measures of subjective sleepiness, contrasted to the no nap condition over the three night shifts. In the case of low precision response time, napping reduced the fatigue effect.

Hypothesis 2:

The second null hypothesis considered the effect that the nap condition would have on the extent of habituation to the night work, as indicated by changes in response or performance profiles over the three days.

$$H_o: \mu PARA(Day)_{nap} = \mu PARA(Day)_{no\ nap}$$

Napping contributed to a certain degree of habituation in beading performance, high precision response time and simple reaction time, as evinced by improvements in

these responses over the course of the three night shifts. Therefore, the null hypothesis is rejected for these variables.

Tympanic and skin temperature and both low and high frequency power responses also demonstrated a significant change over the course of the three night shifts, independent of condition.

Hypothesis 3:

The third and final null hypothesis assessed the effects of the napping versus no napping condition on the circadian-related changes in the performance and response variables, and proposed that any changes in these responses would not be the product of nap intervention.

$$H_o: \mu PARA(Time)_{nap} = \mu PARA(Time)_{no\ nap}$$

The null hypothesis is rejected in the case of beading performance and the two measures of subjective sleepiness, as napping had a significant and beneficial effect on these measures, when compared to the no napping condition.

Independent of condition, the circadian rhythm oscillation resulted in changes in tympanic and skin temperature, all heart rate measures, high and low precision response time and simple reaction time.

CONCLUSIONS

The current research project revealed that the introduction of a flexible nap during the latter half of the night resulted in significant improvements for specific measures consistently over during the three separate night shifts. The significant increases in beading performance evidenced in the nap group was a significant finding in this study: beading was the only true performance indicator and the fact that the nap resulted in higher beading rates has implications for industry in which other such fine motor tasks form part of the chain of production. The fact that the beading technique was not strictly controlled and that the work was self paced may have confounded these results. Alternatively, this self regulation would have facilitated insights into the natural fluctuation in performance, either as a result of the subjects being bored with

the task or as a result of fatigue due to the unnatural hours of work. Nevertheless, the nap and its alerting effect resulted in significantly higher beading rates each shift, relative to the no nap group.

The significantly higher heart rate frequency responses observed for the nap group was also indicative of this group's higher degree of physiological arousal, which in turn could account for the better performance and responses, relative to no napping. The simultaneous reduction in the extent of tympanic temperature decrease (fatigue effect) for the nap group also supports the claim that nap group operated on a higher arousal levels and this translated into improved performance. Low precision response time measures exhibited this heightened level of arousal, as did both measures of subjective sleepiness, with sleepiness ratings being significantly reduced at the end of each shift as a result of the nap being included. The alleviation of subjective sleepiness is an important finding as well in that, if workers are given the opportunity to self regulate their work and rest schedules, then they will chose to rest when it best suits them. This may ultimately result in the sleep quality being higher than in a prescribed napping regime, which will in turn reduce subjective sleepiness later on in the shift. This was indicated by the additional reduction in the extent of fatigue and recovery in both measures. Furthermore, the provision of the nap resulted in improvements in simple reaction times and memory performance, but only at the end of the three shifts. In addition to these beneficial effects, the flexible nap during the early hours of the morning did not significantly hinder recovery sleep during the day in terms of length and quality, compared to the no nap condition. However, no insights into the recovery sleep length and quality were possible.

Despite the aforementioned measures demonstrating a general napping effect, the majority of the variables included in this study, did not. This may have been due to the fact that the shift cycles were not long enough for any effects of the nap intervention to become manifest. However, as already mentioned, the logistics associated with setting up this study did not permit longer shifts. In addition to this, the non-repeated design of the study, in conjunction with the small number of subjects may have limited the statistical power of the study, but logistical challenges and a limited time frame restricted the inclusion repeated-measures design.

Moreover, although the nap was found to be beneficial in some cases, no insight into the length or the quality of the sleep was acquired.

However, in addition to the overt effect of napping on the above mentioned factors, napping also aided in lessening the extent of performance fluctuation, as a product of the natural circadian rhythm. This was evident in the beading performance and the subjective sleepiness ratings of the subjects. The nap provision also assisted in the adaptation of the subjects to the night work in some cases, specifically in beading performance, high precision response time and the simple reaction time responses, where performance improved over the three night shifts, compared to the no nap group. Despite this, it is the opinion of the author that a longer phase of adaptation may have provided more indication of the effects of napping on the circadian-related effects in performance and subject responses as well as role this intervention has in the habituation of subjects to night work.

As with the bulk of napping research that has already been done, concern is raised over the effects of sleep inertia on performance immediately after the nap. Although the current research was not designed to establish and assess the presence and effects of sleep inertia in detail, this phenomenon did become manifest immediately after the nap, particularly for the variables that involved the perception and response to stimuli, namely: high and low precision response time, simple reaction time and memory performance. Subjective sleepiness was also negatively affected immediately post nap. In light of this, industries that involve napping in their fatigue countermeasure programs need to make provision for the period immediately after the nap where performance may be hampered by the remnants of sleep inertia, so as to avoid any loss to production or damage and injury to equipment and personnel.

Napping is a practical and effective means of alleviating the effects of being awake at unnatural hours of the night, specifically through the alleviation of built up sleep pressure and by supporting the natural circadian rhythm. The current study illustrated that the inclusion of a flexible time frame during which workers may nap, may some solutions to the debate over the correct timing and length that night time naps should be. The results of the current study also compare favourably to other such nap studies that have incorporated prescribed napping as an intervention. In

addition to this, the provision of the flexible nap did not compromise or reduce the gross duration of the work shift. This ensured that the effects of the nap on the performance indicators and responses were comparable to those of the rest breaks during the no nap condition, as both conditions had the same gross duration of work time. It does however present logistical challenges to industry regarding work scheduling and the provision of appropriate and acceptable napping quarters, the likes of which need to be dark and comfortable and removed from the work environment. However, improved output and lower strain will compensate for these investments.

RECOMMENDATIONS

The inclusion of flexible napping schemes needs to be explored further, particularly with regard to the time frame in which it is too occur and also the length of the nap period. This should be done in cognisance of the context in which the intervention is to be applied, so that its introduction does not obstruct the workers from the demands of the job or predispose the workers within that context to risk, particularly immediately after nap cessation. The efficacy of this flexible napping scheme as an intervention also needs to be understood in terms of the context in which it is applied, as well as the requirements of the job and the perceptions of industry surrounding such an intervention. Specific issues include shift organisation, where the workers will be able to safely nap, task demands, and the effect such an intervention will have the productivity in the greater scheme of the industry. In addition to this, research in the field of fatigue and shift work should continue to explore plausible, accurate and reliable means of determining fatigue while adopting an integrated and holistic approach to this endeavour.

Future research and outlook

Despite the extensive amount of research performed on the role of napping as a fatigue countermeasure, the current research project has brought to light some crucial questions surrounding the concept of napping that still need to be addressed. In addition to this, considerations regarding the inclusion of napping in industry will also be briefly outlined. Future research should consider flexible versus scheduled

napping on performance during night shift work. With reference to the shift cycle, subsequent research should assess the impact of flexible nap schemes over a shift cycle longer than three days, so as to maximise the chance for the effects of napping to become manifest, when compared to no napping. These longer shift cycles will also be more indicative of those found in the real world work environment. In addition to this, studies of this nature should consider a repeated measures design that expose the same group of subjects to the different conditions, so that the effects of the conditions are more explicit and independent group variance does not confound the observations.

In addition to investigating the impact of napping interventions during 8 hour shifts, consideration needs to be made regarding this intervention's role in assisting workers to cope with longer shift schedules (12 hours). Moreover, the interactive benefits of napping and other fatigue countermeasures such as short periods of exercise (booster breaks), alertness-enhancing medication and light exposure, need to be investigate further in the context of both 8 and 12 hour shifts, both within the laboratory and the field. This must obviously take into consideration the environment and the task demands of the industry. Lastly, the combination of prophylactic napping (prior to the sleep loss) and flexible nap schemes should also be considered as a means of supporting the natural circadian rhythm and alleviating the circadian upsets associated with night shift work.

Napping during the course of the night has been associated with the development of sleep inertia. As such, with respect to flexible nap schemes, the time course dissipation for sleep inertia when individuals nap at different times needs to be monitored and different strategies of combating the detrimental effects of this phenomenon after napping, need to be developed. This is vital for industries that incorporate napping as a fatigue management system.

As regards the task that was given to the subjects during the night shift, future researchers should endeavour to ensure that the task is controlled so that performance reflects the effects of the circadian rhythm as well as the effects of the condition. More real world tasks should be included in such research.

Regarding the measures taken, future research should consider either adopting a wider range of measures or conversely focusing on specific measures when assessing the impact of napping and circadian-related upsets during shift work and sleep loss. Potentially, measures should also be taken more often than was the case in the current study so as to monitor the effect of innate biological rhythms on the responses more accurately. With reference to heart rate and heart rate variability measures, potential areas of research include the effect of flexible nap schemes on the 24 hour cardiac profile of shift workers. Finally, owing to the unexpected results for the saccade latency measures, where napping was found to slow these saccadic responses, further consideration should be given to the effect of napping on saccade latency and other oculomotor responses, as these are crucial indicators of fatigue.

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APPENDICES

APPENDIX A

Recruitment advertisement

Letter to Subjects

Informed consent document

Morningness-Eveningness Questionnaire

Habituation session 1

Habituation session 1: Do's and Dont's

Habituation session 2

Sleep diary

ATTENTION ALL RHODES STUDENTS STAYING FOR APRIL VACATION

Do you sleep 7 - 8 hours each and every night?
Are you a non smoker?
Are keen to see what it is like to work over a night shift?
Do you want to earn some easy money?
Then we have just the study to keep you busy this vacation.

The Department of Human Kinetics and Ergonomics is running two Masters Projects relating to ***SLEEP DEPRIVATION AND SHIFT WORK*** over the April vacation and the study requires between 36 and 48 student volunteers.

Dates: Between **6th April and the 17th of April 2009**

Where: Biopharmaceutics Research Institute Laboratory (above House Keeping services)

Who: the following criteria are required for participation:

- **Males and females, aged between 18 and 26 years**
- **Non smokers**
- **No prior shift work experience**
- **No sleep related disorders (sleep apnea, obstructive sleep disorder, insomnia)**
- **No consumption of alertness enhancing medication**
- **Good physical health**
- **Regular sleeping pattern (at least 7 to 8 hours of sleep a night)**

How long: 3 consecutive night shifts, 8 hour shifts per night

What will you get from it: You will get to see what it is like to work a night shift. We will feed you throughout your shifts too.

You will also receive between **R180 and R220** for your three days work.

What will you have to do: You will be aiding the University in preparing/packing the application forms and prospectuses that need to go out to all potential 2010 students.

What will we test: the benefits of night time napping on your performance to various types of reaction time tasks, as well as your Heart rate, perceptions of sleepiness and eye blink frequency, which is indicative of sleepiness

Where would you stay: you would have to either be in Vacation residences or in your own digs.

IF YOUR INTERESTED IN PARTICIPATING OR WOULD LIKE TO FIND OUT MORE, PLEASE CALL OR EMAIL WES (0823341929 / wesleyrosslombard@gmail.com) OR JONO (0722260430 / j.davy@ru.ac.za).

LETTER TO SUBJECT

Dear …….

Thank you for participating in this project entitled:

"THE EFFECTS OF TWO DIFFRERENT INTERVENTION STRATEGIES (NAPS AND BOOSTER BREAKS) ON PHYSIOLOGICAL AND PERCEPTUAL RESPONSES AND REACTION TIME PERFORMANCE OVER THREE SIMULATED NIGHT SHIFTS"

The Department of Human Kinetics and Ergonomics at Rhodes University is interested in researching the effects of two different intervention strategies on certain physiological, mood and perceptual responses as well as reaction time performance during simulated night shift conditions, compared to a standard night shift condition with standard breaks. An additional comparison will be made between these conditions and a simulated standard day shift.

Intervention 1: The focus of the first intervention will be the effects of napping on the ensuing fatigue from the de-synchronisation of normal circadian rhythms through the introduction of night shift work, and whether or not napping will increase arousal levels and thus yield an improvement in reaction time performance as well as subjective level of sleepiness and mood states.

Procedure

You will be required to partake in two pre test habituation session during which the various procedures and the experimental set ups shall be explained to you in detail. You shall also be made aware of the risks and benefits associated with the research to be done. The entire testing period will be carried out in the Biopharmaceutics Research Institute laboratory. You will be required to take part in three consecutive night (or day) shifts during which you will perform a standard packing task and beading threading task for a duration of 8 hours (standard work shift). At regular, staggered intervals (roughly every 45 minutes), you will stop working. During this time you will either perform a battery of tests or alternatively, you will be permitted to rest, and be provided with a selection of standard sandwiches and a sugar free,

caffeine free soft drink or fruit juice. You will also have unlimited access to water and ablution facilities throughout the shift. The shift will start at 22h00 and finish at 06h00.

The test battery to be administered consists of five different stations. Measures include a simple reaction time task, subjective sleepiness and mood state questionnaires, critical flicker fusion frequency, saccade latency and precision task performance as well as a memory test. Throughout the shift, Heart rate variability will be recorded through the use of a Suunto® T6 heart rate memory belt, and regular periodic tympanic temperatures will be recorded.

Once the shift has ended, and once you have completed the post shift test battery, you will be free to return to your place of residence and sleep for the remainder of the day. You are required and encouraged to attempt to sleep a minimum of 5.5 hours during the course of the day, and report for work promptly at 21h00, at which point you will be fed a standard pre-shift meal.

Requirements

Prior to testing, we ask that you refrain from the following:

- Consumption of alcohol and drugs 48 hours prior
- Caffeine ingestion 24 hours prior
- Vigorous physical activity 24 hours prior
- Napping during the morning or afternoon of the first day

Prior to testing, we ask that you:

- Report any illnesses or medication intake of any sort
- Maintain a normal (regular) sleeping pattern up to the start of testing
- Complete a daily sleep diary 3 days prior to, during testing and 3 days after
- Ask any questions you may have at any time
- Bring your bank details to the 2nd session

At the habituation session, the following measurements and information will be taken:

Stature; Mass; Age; Education level, Race

You will also be required to fill out a Morningness – Eveningness Questionnaire (Horne and Östberg, 1976). The results of this assessment will be used as the criteria to classify and evenly distribute subjects across the different conditions, according to chronotype. A Sleep disorders questionnaire will also be administered to identify subjects that may potentially affect the overall results negatively. You will also be required to fill out a sleep diary for three days prior to the start of your condition. You will also be required to keep a similar diary during the testing period.

If, at any period of time during the testing procedure, you feel the need to withdraw from the study **for whatever reason**, you are free to inform the researchers that you do not wish to continue to take part in the research any more. You are under no obligation to stay against your will, or complete testing should you feel the need to discontinue from the study. All information obtained will be **stored confidentially** and all data will be coded so ensure your **anonymity**. We thank you for your interest in our research projects, please feel free to ask us any questions you may have about the process at any time.

Yours sincerely,

Jonathan Davy
MSc Student
0722260430

Wesley Ross Lombard
MSc Student
0823341929

SUBJECT CONSENT FORM

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

"THE EFFECTS OF A 1 HOUR NAP ON PHYSIOLOGICAL AND PERCEPTUAL RESPONSES AND REACTION TIME *PERFORMANCE* **OVER THREE SIMULATED NIGHT SHIFTS"**

"THE EFFECTS OF PERIODIC "BOOSTER BREAKS" ON PHYSIOLOGICAL AND PERCEPTUAL RESPONSES AND REACTION TIME PERFORMANCE OVER THREE SIMULATED NIGHT SHIFTS"

Do hereby give my consent to act as a subject 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 or for teaching 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.

SUBJECT (OR LEGAL REPRESENTATIVE):

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

PERSON ADMINISTERING INFORMED CONSENT:

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

WITNESS:

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

MORNINGNESS-EVENING QUESTIONNAIRE

(Self Assessment Version)

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

HABITUATION SESSION 1

1. **Welcome and Introduction**
2. **Handout subject letter**
3. **Explanation of project**: Introduction about shift work and role of napping and booster breaks as fatigue countermeasures
4. **Experimental set up**; 3 days of work, most = night shifts, quarter = day shift
5. **Mon – Wed**: group 1: 6 men, 6 women.

   12 subjects = divided into 3 groups

   1 subgroup of 4 = nappers

   1 subgroup of 4 = work normal shift

   1 subgroup of 4 = booster breaks
6. **Thur – Sat** = as above, **Sun – Tues** = as above
7. Shift start at 21h00 = come and get fed and re briefed. Pre shift testing and then you work from 22h00 – 06h00.
8. Work periods = 45 minutes to 70 minutess. Perform a packing task and a bead threading task. When you are not working you will either be performing a 15 min test battery, or resting and being fed.
9. In the case of the **nap condition** = no official breaks. After 01h00 to 03h00 = you can nap any time for a max of 1 hour. You will be exposed to a pre nap and post nap test
10. Or you will be exposed to a **booster break**, each hour for 7.5 minutes = do basic exercises and stretches.

11. **Standard night shift** = work normal shift schedule = 2 x 15 min breaks and 1 x 30 min break. You will just sit quietly and read magazines and eat during your break.
12. **Equipment and testing**: we will perform tests on you throughout the night = monitor progress
    a. HR: using this belt that fits around your chest, we will measure your heart rate throughout the shift.
    b. Tympanic temperature
    c. Skin temperature
    d. High and low precision response time
    e. High and low precision target deviation
    f. Simple reaction time
    g. Subjective sleepiness: Wits sleep scale, Karolinska Sleepiness scale,
    h. Saccade latency during precision performance
    i. Critical flicker fusion frequency
    j. Memory test: Simple word recall test
    k. Sleep diaries: 3 days before, during testing, 3 days after testing
13. **Questions**:
14. **Informed consent**
15. **Morningness eveningness questionnaire**: explanation: answer as honestly as you can
16. **Take anthropometrics**
17. Indicate when next habituation session can happen: Thursday or Friday: further 30 mins, from 08h30 – 12h30 and 14h00 – 17h00 both days

HABITUATION SESSION 1

18. **Don’ts**:
    a. No alcohol or drugs 48 hours before testing
    b. No caffeine 24 hours before testing and no caffeine during testing – no energy drinks like red bull or coffee
    c. No alertness enhancing drugs – bioplus, energy tablets etc
    d. No smoking
    e. No napping on the day or afternoon before you report for the night shift
19. **Dos**:
    a. Sleep a minimum of 5.5 hours after your night shift
    b. Ask questions
    c. Feel free to leave the study if you are any stage not comfortable with the study
    d. Please report any injuries, illnesses or medicines being taken to the researchers
    e. Women that are pregnant, are encourage to inform the researchers as shift work will have a negative impact on developing baby

HABITUATION SESSION 2:

1. **Subjects arrive at the BRI lab:** welcome and tour of the lab.
2. **Information RE which shifts each subject is to work, dates, times and conditions:** each subject is informed as to which group they have been assigned too. They are informed of the dates that they are required to work as well as the times:
    a. **Night workers:** dates range from the 6th to the 14th of April. Subjects are informed that they must report to the lab at 21h00 (for pre shift meal) for each of their three shifts. They are reminded of the following:
        i. **No caffeine consumption of any form**
        ii. **No alcohol or drug consumption**
        iii. **No vigorous exercise**
        iv. **No napping prior to first shift**
        v. **Minimum of 5.5 hours slept post shift (in one block preferably)**
    b. **Each subject is then informed of the particular condition in which they will be required to work:**
        i. Nap condition: each subject is instructed that they will be required to work from 22h00 to 01h00 at which point they will have the choice to have a 1 hour nap any time between 01h00 and 03h00 am. They will be permitted to lie down in a darkened room for 1 hour, after which the researcher will wake them by gently calling their names. Prior to the nap, each subject will undergo a test battery. A post test will also be administered.

ii. The Booster break condition: each subject will perform a short battery of light exercises (stretches and basic stepping) for a period of 7.5 mins (each hour).

iii. Standard night shift: each subject will perform a standard 8 hour shift. Subjects will be privy to 2 x 15 minute breaks and 1 x 30 minute mid-shift break, during which subjects will be fed and be permitted to sit quietly in a separate room and read magazines and interact in a very sedate manner.

c. **Each subject will then be exposed to the beading task and the application packing**

d. **Each subject will then be exposed to the battery of tests:**

   i. **Eye tracker and precision task performance**

   ii. **Memory task**

   iii. **Simple reaction time, Wits Sleepiness scale, Karolinska Sleepiness scale**

   iv. **CFFF, Tympanic temperature and Infra red temperature taken of the forehead**

   v. **Heart rate**

3. **Subjects will then be reminded of when they will be working and presented with a shift reminder slip. The sleep diary will then be presented and explained to each subjects. Subjects were also instructed when to fill out the diary and sent on their way.**

SLEEP DIARY

1. **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 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.

	PRIOR TO TESTING			**DURING TESTING**			**AFTER TESTING**		
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8	DAY 9
Time you went to bed									
Number of times you woke up									
Time you woke up									
Total sleep time (Hrs/mins)									
Overall perceived quality of sleep									

1= very poor **2** = poor **3** = average **4** = good **5** = very good

3. **ADDITIONAL INFORMATION**

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

	PRIOR TO TESTING			**DURING TESTING**			**AFTER TESTING**		
	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8	DAY 9
Drank caffeinated drinks (How many)									
Napped (How long)									
Exercise (How long)									
Drank alcohol (How many units)									
Took any medication									

APPENDIX B

Night shift condition arrangements

Day shift condition arrangements

Karolinska Sleepiness Scale

Wits Sleepiness Scale

Example of Simple word recall tasks

Hours	No Nap Condition	Nap Condition	Exercise Condition
21H00			
21H15		PRE SHIFT TEST 2.0	
21H30			PRE SHIFT TEST 3.0
21H45	PRE SHIFT TEST 1.0		
22H00 - 22H15	SHIFT STARTS	SHIFT STARTS	SHIFT STARTS
22H15 - 22H30		TEST 2.1	
22H30 - 22H45			TEST 3.1
22H45 - 23H00	TEST 1.1		
23H00 -23H15			BOOSTER BREAK
23H15 - 23H30			
23H30 - 23H45			
23H45 - 00H00	TEA BREAK - FEED	FEED	FEED
00H00 - 00H15			BOOSTER BREAK
00H15 - 00H30		TEST 2.2	
00H30 - 00H45			TEST 3.2
00H45 - 01H00	TEST 1.2		
01H00 - 01H15			
01H15 - 01H30			BOOSTER BREAK
01H30 - 01H45			
01H45 - 02H00	LONG BREAK - FEED	FEEDING WITHOUT BREAK	BREAK WITH FEED
02H00 - 02H15	LONG BREAK - FEED		
02H15 - 02H30		TEST 2.3	
02H30 - 02H45			TEST 3.3
02H45 - 03H00			BOOSTER BREAK
03H00 - 03H15	TEST 1.3		
03H15 - 03H30			
03H30 -03H45			
03H45 - 04H00			FEED
04H00 - 04H15	TEA BREAK - FEED	FEED	BOOSTER BREAK
04H15 - 04H30		TEST 2.5	
04H30 - 04H45			TEST 3.4
04H45 - 05H00	TEST 1.4		
05H00 - 05H15			BOOSTER BREAK
05H15 -05H30			
05h30-05h45			
05H45 -06H00	SHIFT ENDS	TEST 2.6 shift ends	SHIFT ENDS
06H00-06H15			TEST 3.5
06H15 - 06H30	TEST 1.5		

DAY SHIFT CONDITION ARRANGMENTS			
Hours			
07H00-07H15			
07H15-07H30		PRE SHIFT TEST 1.0	
07H30-07H45			PRE SHIFT TEST 1.0
07H45-08H00	PRE SHIFT TEST 1.0		
08H00-08H15	SHIFT STARTS	SHIFT STARTS	SHIFT STARTS
08H15-08H30		TEST 1.1	
08H30-08H45			TEST 1.1
08H45-09H00	TEST 1.1		
09H00-09H15			
09H15-09H30			
09H30-09H45			
09H45-10H00	TEA BREAK - FEED	TEA BREAK – FEED	TEA BREAK - FEED
10H00-10H15			
10H15-10H30		TEST 1.2	
10H30-10H45			TEST 1.2
10H45-11H00	TEST 1.2		
11H00-11H15			
11H15-11H30			
11H30-11H45			
11H45-12H00	LONG BREAK - FEED	LONG BREAK – FEED	LONG BREAK - FEED
12H00-12H15	LONG BREAK - FEED	LONG BREAK – FEED	LONG BREAK - FEED
12H15-12H30			
12H30-12H45		TEST 1.3	
12H45-13H00			TEST 1.3
13H00-13H15	TEST 1.3		
13H15-13H30			
13H30-13H45			
13H45-14H00			
14H00-14H15	TEA BREAK - FEED	TEA BREAK – FEED	TEA BREAK - FEED
14H15-14H30			
14H30-14H45		TEST 1.4	
14H45-15H00			TEST 1.4
15H00-15H15	TEST 1.4		
15H15-15H30			
15H30-15H45			
15H45-16H00	SHIFT ENDS	TEST 1.5	SHIFT ENDS
16H00-16H15			TEST 1.5
16H15-16H30	TEST 1.5		
16H30-16H45			

Karolinska sleep scale

1 extremely alert

2 very alert

3 alert

4 rather alert

5 neither alert nor sleepy

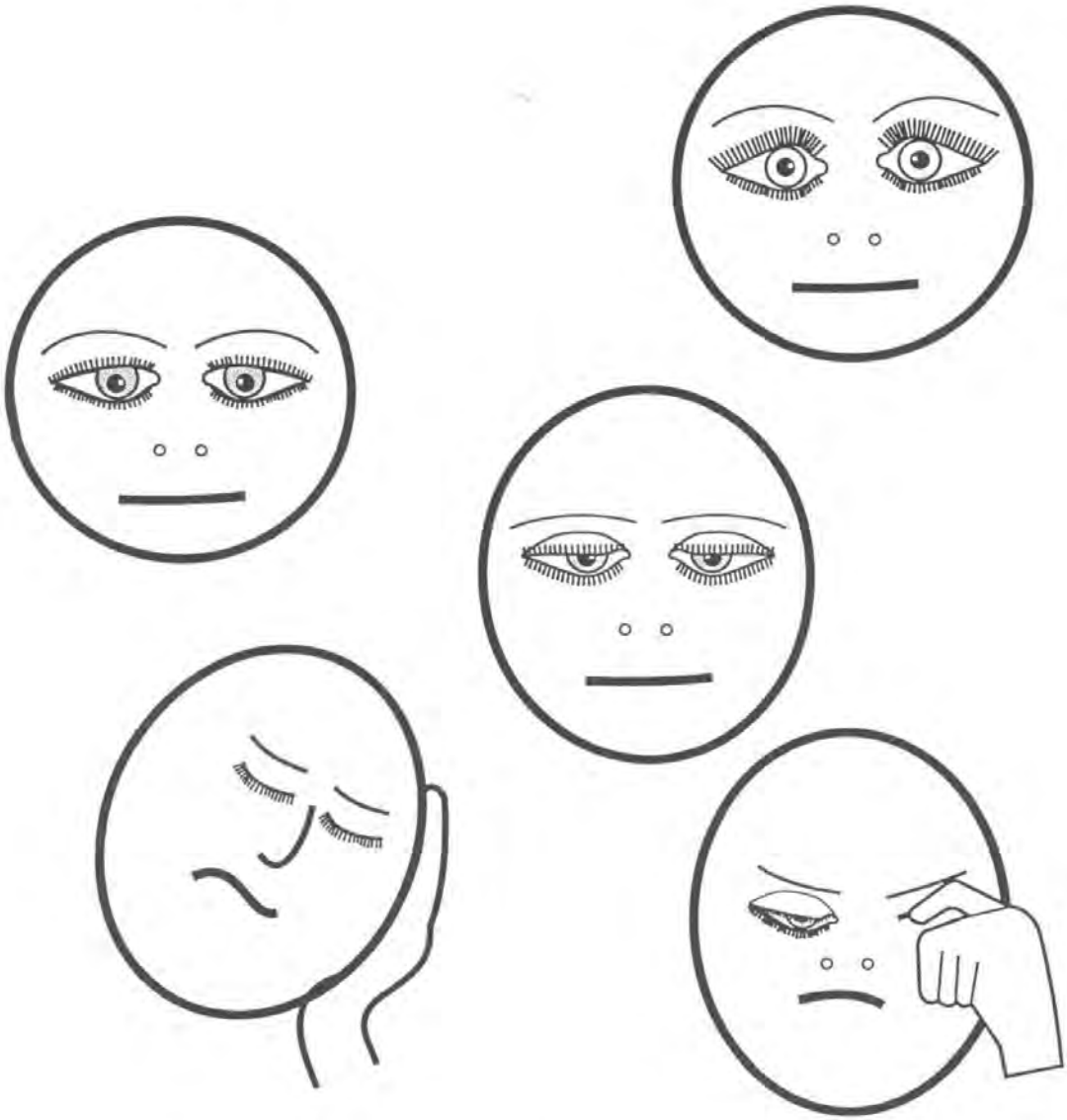
6 some signs of sleepiness

7 sleepy, no effort to stay awake

8 sleepy, some effort to stay awake

9 very sleepy, great effort to stay awake, fighting sleep

Wits Sleepiness Scale



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MEMORY TASK 1

HORSE	WEATHER
RIGGING	BANDAGE
PRESIDENT	RUBBER
MORNING	NIECE
FIGHT	INTERNET
MOTHER	VIRUS

MEMORY 2

FATHER	DIFFICULT
AMBULANCE	COMPUTER
TELEPHONE	BICYCLE
MARATHON	FARM
VOLUME	RAIN
INSECT	DRAMA

APPENDIX C

Table 1: Statistical effects for beading performances for the no nap and day conditions

Repeated Measures Analysis of Variance (Beading performance) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	19298.65	1	19298.65	367.2163	0.000000
Condition	8.15	1	8.15	0.1551	0.697527
Error	1156.19	22	52.55		
Days	205.01	2	102.51	6.5622	0.003205
Days*Condition	5.91	2	2.95	0.1890	0.828438
Error	687.31	44	15.62		
Time	14.51	2	7.25	0.5021	0.608660
Time*Condition	57.11	2	28.55	1.9769	0.150603
Error	635.51	44	14.44		
Days*Measures	61.88	4	15.47	1.5160	0.204429
Days*Measures*Condition	41.44	4	10.36	1.0152	0.404049
Error	898.01	88	10.20		

Table 2: Statistical effects for heart rate frequency data for all three conditions

Repeated Measures Analysis of Variance (Heart rate frequency) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	410.4818	1	410.4818	38475.16	0.000000
Condition	0.0589	2	0.0294	2.76	0.078020
Error	0.3521	33	0.0107		
Days	0.0183	2	0.0091	1.66	0.198857
Days*Condition	0.0081	4	0.0020	0.37	0.832357
Error	0.3646	66	0.0055		
measures	0.2231	3	0.0744	15.26	0.000000
Time*Condition	0.0841	6	0.0140	2.88	0.012615
Error	0.4825	99	0.0049		
Days*Time	0.0219	6	0.0037	1.15	0.335145
Days*Time*Condition	0.0407	12	0.0034	1.07	0.389316
Error	0.6289	198	0.0032		

Table 3: Statistical effects for low precision response times for the nap and day condition comparison

Repeated Measures Analysis of Variance (Low precision response time) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	280.7634	1	280.7634	20267.90	0.000000
Condition	0.0144	1	0.0144	1.04	0.319605
Error	0.3048	22	0.0139		
DAYS	0.0192	2	0.0096	0.89	0.419625
DAYS*Condition	0.0081	2	0.0041	0.38	0.689432
Error	0.4761	44	0.0108		
MEASURES	0.1133	3	0.0378	3.69	0.016075
MEASURES*Condition	0.0565	3	0.0188	1.84	0.148093
Error	0.6753	66	0.0102		
DAYS*MEASURES	0.0314	6	0.0052	0.65	0.688440
DAYS*MEASURES*Condition	0.0178	6	0.0030	0.37	0.897247
Error	1.0589	132	0.0080		

Table 4: Statistical effects for low precision response times for the no nap and day condition comparison

Repeated Measures Analysis of Variance (LP RT) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	288.2450	1	288.2450	22483.46	0.000000
Condition	0.1167	1	0.1167	9.10	0.006336*
Error	0.2820	22	0.0128		
DAYS	0.0098	2	0.0049	0.51	0.602202
DAYS*Condition	0.0025	2	0.0013	0.13	0.876265
Error	0.4213	44	0.0096		
MEASURES	0.0556	3	0.0185	1.97	0.127205
MEASURES*Condition	0.0959	3	0.0320	3.40	0.022864
Error	0.6215	66	0.0094		
DAYS*MEASURES	0.0309	6	0.0052	0.62	0.710340
DAYS*MEASURES*Condition	0.0357	6	0.0060	0.72	0.632697
Error	1.0884	132	0.0082		

Table 5: Statistical effects for sleepiness ratings (KSS) for the nap and day condition comparison

Repeated Measures Analysis of Variance (Karolinka Sleepiness Scale) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	522.1540	1	522.1540	1142.690	0.000000
Condition	1.8819	1	1.8819	4.118	0.054686
Error	10.0529	22	0.4570		
DAYS	1.1131	2	0.5566	1.608	0.211920
DAYS*Condition	0.4715	2	0.2358	0.681	0.511382
Error	15.2333	44	0.3462		
MEASURES	22.1390	3	7.3797	23.183	0.000000
MEASURES*Condition	2.0419	3	0.6806	2.138	0.103746
Error	21.0092	66	0.3183		
DAYS*MEASURES	2.6334	6	0.4389	2.162	0.050597
DAYS*MEASURES*Condition	0.6158	6	0.1026	0.506	0.803228
Error	26.7954	132	0.2030		

Table 6: Statistical effects for sleepiness ratings (WSS) for the nap and day condition comparison

Repeated Measures Analysis of Variance (Wits Sleepiness Scale) Sigma-restricted parameterization Effective hypothesis decomposition					
	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	481.5772	1	481.5772	1042.379	0.000000
Condition	0.0918	1	0.0918	0.199	0.660173
Error	10.1640	22	0.4620		
DAYS	2.8630	2	1.4315	4.288	0.019890
DAYS*Condition	0.6698	2	0.3349	1.003	0.374933
Error	14.6890	44	0.3338		
MEASURES	17.4250	3	5.8083	21.339	0.000000
MEASURES*Condition	1.5486	3	0.5162	1.896	0.138758
Error	17.9649	66	0.2722		
DAYS*MEASURES	3.3630	6	0.5605	3.083	0.007396
DAYS*MEASURES*Condition	0.6447	6	0.1075	0.591	0.736939
Error	23.9946	132	0.1818		