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Measuring Adaptation to Shiftwork

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Submitted as a requirement for the degree of Ph.D.
In the Faculty of Medicine, University of Adelaide.
Submitted December 1998

Table of Contents

Experimental Section One

Experimental Section Two

Experimental Section Three

Abstract

Shiftwork by its nature results in disruption to the body's normal rhythms. In particular sleep-wake rhythms are altered so that workers are often attempting to sleep and perform at times of day when the ability to do so is reduced. The aims of this thesis were three fold: to quantify the effects of sleep deprivation on performance in a way that could be easily understood, to validate less invasive methods of objectively measuring the sleep wake activity of shiftworkers and to investigate the effects of shiftwork on both sleep and performance in the laboratory and the field.

Chapter two compared the performance impairment due to sleep deprivation with the performance impairment observed with alcohol intoxication. From this study it was found that the performance impairment observed at a blood alcohol concentration of 0.05% was equivalent to the performance impairment resulting from 18 hours of sustained wakefulness. After 24 hours of sustained wakefulness performance was impaired equivalent to a 0.1% BAC equivalent.

Chapter three is a methodological chapter in which the use of actigraphic measures of sleep-wake activity during a simulated shiftwork schedule was compared to traditional electrophysiological measures. This study revealed that, while actigraphy is a valid measure of sleep-wake in a simulated shiftwork environment, some caution should be used for more specific measures such as sleep efficiency. In addition, age and timing of sleep play a significant role in the correlation between EEG and actigraphy.

Chapter four examined the effects of a simulated 12-hour shift rotation on the self-selected sleep duration and quality of younger and older individuals. The results of this study showed that individuals were able to sleep as long if not longer during the day following a 12-hour night shift as during the night following a 12-hour day shift. However, the sleep durations observed in this study for both night and day-time sleep periods were in most cases shorter than those observed for non-shiftworkers.

Chapter five detailed the performance of older and younger subjects during a simulated 12-hour shift rotation. The results of this study indicate that, there was no significant difference in mean performance between 12-hour day and night shifts. However, there was a significant difference in mean performance and a difference in the pattern of performance across shifts between young and older subjects on a 12-hour shift rotation. In addition, older subjects were more sensitive to time of day and or sleep disruption than younger subjects.

Chapters six and seven reported the results of a large field-based study investigating the effects of irregular hours of work on the sleep of train drivers. These studies showed that the circadian rhythm of sleep-wake was maintained when on irregular shift schedules. Specifically drivers slept proportionally more during the night-time compared to the day-time regardless of their work schedule and that this was influenced little by individual factors for example age, domestic status and circadian type. Chapter seven examined the amount of sleep as a function of break onset and showed that the probability of sleep during the day-time was low regardless of the time of break onset and that the amount of sleep accumulated during a break between consecutive shifts varied as a function of break onset and break duration. Breaks of only 8 hours in duration resulted in drivers obtaining only 4-5 hours of sleep between shifts. It was hypothesised that this may lead to significant reductions in alertness and performance and also significant cumulative sleep deprivation over consecutive shifts.

In summary, the results from the work contained in this thesis suggest that the performance impairment of sleep deprivation of as little as 18 hours is equivalent to the performance impairment observed at a blood alcohol concentration of 0.05%. It was shown that actigraphy is a valid and reliable method of determining sleep-wake in shiftworkers. In the work related experimental studies it was found that during a 12-hour shift rotation subjects sleep was shortened and that neuro-behavioural performance was reduced during the early morning regardless of whether at the beginning or end of a shift, and that the decrement was more pronounced in older compared to younger subjects. The sleep of train drivers on irregular shift schedules maintained the normal circadian rhythmicity and this was influenced only slightly by work schedule, break duration and other individual factors. In conclusion, the sleep disruption resulting from shiftwork both in the field and laboratory is significant and may have serious implications for both worker health and safety.

I certify that this thesis does not incorporate without acknowledgement, any material previously submitted for a degree or diploma in any University; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except were due reference is made in the text.

I consent to this thesis being made available for photocopying and loan if accepted for the award of the degree.

Signed

Kathryn Jean Reid ..15/12/98..........

Acknowledgements

I would like to thank my supervisors Drew Dawson and Dave Kennaway for all their support and encouragement over the past 4 years. In addition I would also like to thank my family and friends particularly Stew and Erik, for putting up with me, especially for the last 6 months.

I would also like to thank everyone at the Centre for Sleep Research both past and present. Without their help it would not have been possible to complete the type of studies contained in this thesis. I would especially like to thank Mari-anne Kelly, Ruth Bateson and Greg Roach for their help with both the field trials and laboratory based studies.

Lastly, but by no means least I would like to thank both my parents and my Nanna, for without their love and support none of this would have been possible.

No human research is possible without the dedication and interest of all the subjects who volunteer to take part.

Thank you

“I am still learning”

Michael Angelo

Chapter One

Introduction, Background and Justification

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1.1 Introduction

Shiftwork by its nature results in disruption to the body's normal rhythms. In particular sleep-wake rhythms are altered so that workers are often attempting to sleep and perform at times of day when the ability to do so is reduced. The current thesis investigates the consequences of shiftwork related disruption to circadian rhythms, particularly those of sleep and performance.

This section will discuss shiftwork and circadian rhythms with particular emphasis on the rhythms of sleep and performance. Specifically it will define shiftwork, who does it and why we have shiftwork, shift types and introduce some of the possible problems associated with shiftwork. This will be followed by an examination of circadian rhythms; what are they how are they generated and the endogenous and exogenous components. Special emphasis will be given to discussing sleep including circadian and homeostatic components, as well as factors like the circadian rhythm in sleep propensity and sleep duration and models of sleep regulation. Another area of particular interest is performance. This section discusses circadian rhythms in performance, techniques for measuring performance and also difficulties in measuring performance both in laboratory and in the field.

Most importantly this section will discuss the influence of shiftwork on circadian rhythms generally and then more specifically the influence of shiftwork on sleep and performance. An overall theme throughout this section will be the influence of individual differences on the adaptation to shiftwork and their influence on sleep and performance. Individual factors include both biological factors for example age and more psychological or psycho-social factors for example marital status, number of children, gender and morningness-eveningness type.

Finally there will be a discussion of sleep deprivation and restriction studies in an attempt to highlight the importance of this type of study in identifying the possible implications of sleep loss for shiftworkers.

1.2 Shiftwork

It is estimated that approximately 15-20% of workers are currently employed in some form of shiftwork and it is believed this will increase in the future (Dumont, 1985; Australian Bureau of Statistics, 1993). In Australia over the past four years the number of shiftworkers has increased by just over one hundred thousand with the majority of this increase involving female shiftworkers (Australian Bureau of Statistics, 1993, 1997).

Traditional work schedules are typically forty hours per week performed during the daylight hours 0800-0900 hours to 1600-1700 hours, however, many industries operate outside of these times. As a result of economic and customer demand a wide variety of different work schedules have evolved. Research from the United States and Australia suggest that there are thousands of different shiftwork schedules currently in use (Rogers *et al.*, 1997; Smith *et al.*, 1998).

Schedules vary significantly between and within industries and occupations. Since shift schedules are generally determined at individual worksites, diverse schedules are found within single industries, reflecting geographic and regional differences. Furthermore, work schedules at particular sites are influenced by regional laws and regulations, tradition in a particular occupation or industry, labour costs and the availability of skilled labour.

As an example, the most common work schedule in the manufacturing industry involves working five or six days on a single shift, followed by two days off. This type of schedule generally entails two (day and evening or day and night) or three (day, evening and night) shifts per day of either an eight or twelve hour duration. These may be fixed, rotating or a combination of both.

Alternatively, shiftwork systems may cover continuous operations seven days a week, such as in the service sector or in continuous-process manufacturing. The scheduled work day typically ranges from eight to twelve hours and shifts may be fixed, partially fixed or rotating. Under these circumstances shift rotation may be rapid (three days) or long (four weeks) and it may proceed forward (day, evening, night) or backward (day, night, evening).

Other than 'standard' shiftwork schedules there are a variety of schedules which appear to be increasing in popularity. For example, the compressed work week involves employees working approximately forty hours per week in less than five days and is common in various entertainment industries. Additionally, irregular scheduling, in which shifts are variable and erratic, are popular in the transportation industry (Rogers *et al.*, 1997).

As shiftwork becomes a more common work practice in many industries there is often a lack of awareness within industry and the community as to many of the indirect costs associated with shiftwork. For example, as a result of work outside of the 'normal' hours, shiftworkers are often required to rearrange their daily activities, in particular sleep-wake and social activities. The disruption of 'normal' rhythmicity may have a serious impact on sleep-wake, alertness and performance. In addition, there may be stress created by having to juggle social and domestic commitments (Lushington *et al.*, 1997). This in turn may reduce sleep, motivation and therefore worker performance. There have also been links between sleep disruption and reduced immune function (Moldofsky *et al.*, 1989). Shiftwork has also been associated with an increase in gastrointestinal disorders, cardiac problems, reduced birth weights, increases in miscarriage and other health related issues (Harrington, 1978; Knutsson *et al.*, 1986; Armstrong *et al.*, 1989). These factors may in turn; increase absenteeism due to sick days or workers may need to take additional days off to recover from sleep loss or to participate in social and domestic activities that are otherwise restricted. While the economic benefits of shiftwork are clear (Bosworth and Dawkins, 1981) there are significant safety (Mitler *et al.*, 1988), health and emotional costs (Harrington, 1978; Monk and Folkard, 1992) that may often be over looked.

Many of the indirect costs associated with shiftwork, particularly those of health, sleep and alertness are significantly influenced by the accompanying disruption to circadian rhythms. It is therefore necessary to have an understanding of what circadian rhythms are, how they are generated and what role they play in adaptation to shiftwork.

1.3 Circadian Rhythms

Circadian rhythms are fluctuations that occur in most bodily functions (e.g. sleep-wake, core temperature, hormone levels etc) that recur with a periodicity of approximately 24 hours.

Under free running conditions, where external entraining influences (zeitgebers) are removed, the overt physiological rhythms exhibit a period length representative of the period of the underlying pacemakers (free run period). The period of the underlying pacemakers may vary between individuals and species but is typically between 23-25 hours (Moore-ede *et al.*, 1982). There is also a shortening of period across the life span of most species (Weitzman *et al.*, 1982; Morin, 1988; Moore-Ede *et al.*, 1982).

On the basis of comprehensive mammalian and several human studies, it is generally considered that circadian pacemakers are located in the suprachiasmatic nuclei (SCN) (Klein *et al.*, 1991; Ralph *et al.*, 1990). The suprachiasmatic nuclei (SCN) are a pair of structures consisting of a cluster of thousands of nerve cells and are located in the anterior ventral hypothalamus (Moore-Ede *et al.*, 1982). The SCN is thought to be the dominant pacemaker, however, there may be additional pacemaker sites in other hypothalamic and brain locations (see review by Moore- Ede *et al.*, 1982; Mistleburger *et al.*, 1989). In addition, there is some evidence to suggest further CNS pacemaker activity in the gastrointestinal and renal systems (Mistleburger *et al.*, 1989, Rusak *et al.*, 1979).

Circadian rhythms are influenced by both the endogenous pacemaker and exogenous or entraining factors (zeitgebers). The strongest of these entraining factors is the light-dark cycle, followed closely by social time cues, for example clock time and meals. The light-dark cycle acts predominantly on the SCN via the retinohypothalamic pathways (Moore, 1973; Card and Moore, 1991) although there is recent evidence in humans suggesting a non-retinal pathway for light (Campbell and Murphy, 1998).

Other activities that may acutely influence circadian rhythms are sleep-wake activity, ambient temperature, food and hot/cold showers. The act of going to sleep reduces core temperature, the cessation of fluid and food intake during sleep affects urine flow and the plasma insulin rhythm respectively (Moore-Ede *et al.*, 1982).

Together both endogenous (SCN) and exogenous (light/dark cycle, social) components create the overt circadian rhythm. For example the endogenous rhythm of core temperature would be effected by a sauna and a plunge into an icy pool (exogenous components). These activities would cause fluctuations in the endogenous component of the rhythm and when temperature is measured we seen these fluctuations in the overt rhythm (see figure 1 below). The influence of the hot and cold conditions are called "masking effects" as they alter or mask the endogenous component of the temperature rhythm. Because of the body's homeostatic control of temperature when it is placed in conditions of hot or cold it will compensate and alter core temperature accordingly.

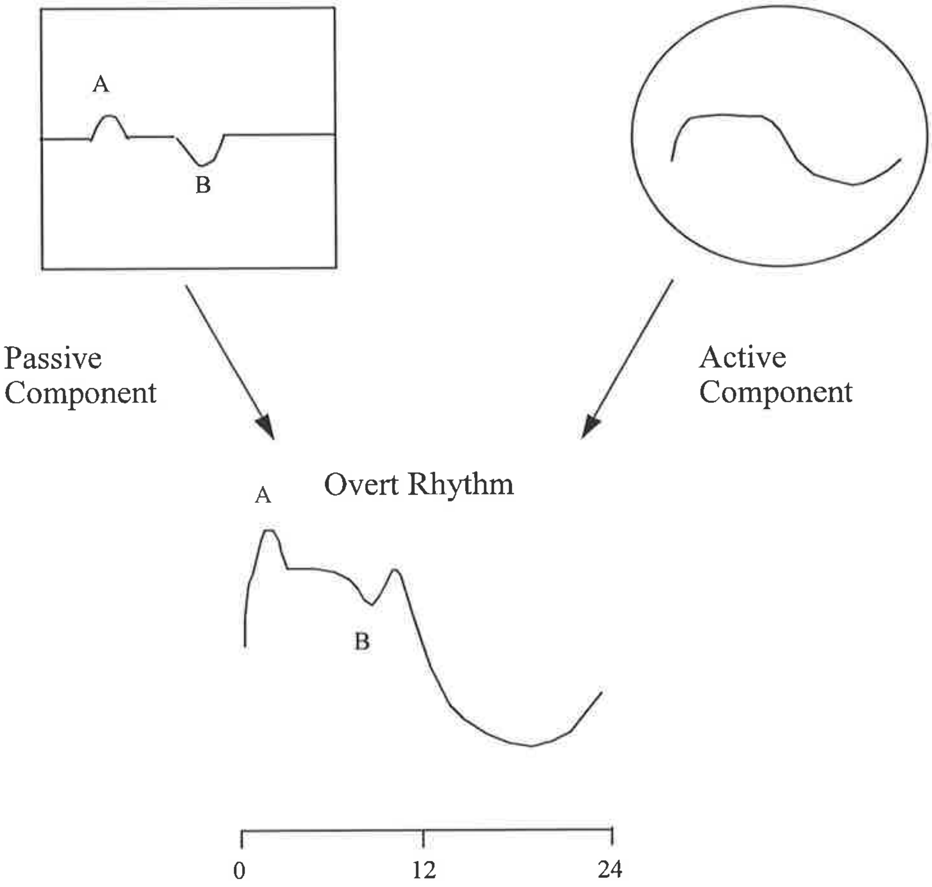

Figure 1. The contributions of exogenous influences and endogenous oscillations to an overt rhythm such as core body temperature. A represents an increase in body temperature due to a hot shower in the morning and B represents a drop in core temperature due to eating a litre of ice-cream. The passive components will change body temperature whenever they occur. Right the rhythmic pattern of core temperature as timed by endogenous circadian oscillators. The measured overt rhythm (below) reflects both the endogenous and the exogenous influences. (Moore-Ede *et al.*, 1982)

Phase Differences Between Measures

Although many bodily functions display circadian rhythms not all functions peak and trough at the same time. For example in normally entrained humans on a regular light/dark cycle the hormone melatonin has a peak during the night-time and is low during the day (Waldhauser *et al.*, 1984), whereas the core body temperature rhythm peaks during the day and is at a low during the night (Aschoff *et al.*, 1981; Cagnacci *et al.*, 1995). Both of these rhythms are controlled by the same central pacemaker, but are able to peak and trough at different times.

Shiftworkers often experience problems as a result of phase differences in various rhythms as the pacemaker is unable to quickly adjust to the shift. For example shiftworkers often sleep during the day-time (rather than at night) and many of the body's other rhythms that help prepare the body for sleep, for example lower core temperature are still present at night. This mismatch between rhythms is likely a reason why many shiftworkers experience poor day-time sleep and reduced performance at night (Åkerstedt, 1995b; Folkard *et al.*, 1981). This is further complicated because not all rhythms entrain to the new environment at the same rate some may shift an hour a day while others may shift more rapidly or slowly (Wever, 1985).

Individual Differences in Circadian Rhythms

The endogenous phase position of circadian rhythms differs among individuals. Several factors have been identified in which the circadian rhythms of individuals consistently differ, for example age and morning-eveningness type. As a result of the differences in circadian rhythms for some individuals there are changes in the phase position and amplitude of rhythms, for example those of sleep, core temperature and other bodily functions (see below for more details). These changes also result in differences in adjustment as a result of disruption to circadian rhythms like those associated with shiftwork. The rest of this section will discuss two of these factors that are of particular interest for this thesis, age and morning-eveningness.

Age

There is evidence that the circadian rhythms of older individuals differ from those of younger individuals. As people age there is a reduction in the amplitude and lability as well as an advance in the phase and shortened period of circadian rhythms (Myers and Badia, 1995; Weitzman *et al.* 1982; Czeisler *et al.*, 1992).

Wever (1979) reported that the strength of the mutual coupling between rhythms diminished with age. During temporal isolation subjects older than 35-45 showed a tendency to undergo internal desynchronisation of the sleep-wake and temperature rhythms. These alterations with age in the amplitude of circadian rhythms may alter adaptation to shiftwork. In the following sections the differences in sleep-wake and performance of older and younger individuals will be discussed as will the influence of age on shiftworker adaptation and the subsequent influence on sleep and performance.

Another factor that has been identified to influence the phase position of circadian rhythms is morningness and eveningness type and research has shown that as people age they may have a tendency towards being more morning type (Torsvall and Åkerstedt, 1980).

Morning-Eveningness

Morning-eveningness type is typically determined by questionnaire, and identifies individuals who have a preference for going to sleep early and waking early (morning-type), as opposed to those who prefer to sleep late and wake late (evening-type). This preference for sleep times is reflected in a difference in the phase position of the circadian rhythm of core temperature, with the maximum in core temperature occurring earlier in morning types than in evening types (Breithaupt *et al.*, 1981; Folkard *et al.*, 1979). Hildebrandt *et al.* (1979) reported that morning-types also have lower amplitude rhythms than evening types.

A questionnaire designed to identify morning and evening types was first published in the English language by Horne and Ostberg (1976) although there were also earlier versions of the questionnaire in other languages (Ostberg, 1973). It has been suggested that due to the influence of cultural differences the questionnaire should be modified for specific cultural and ethnic groups.

There has also been debate about the occurrence of morningness or eveningness types. This may be a result of several studies that have reported different distributions of each type in various populations. Posey and Ford (1981) administered the Horne and Ostberg (1976) questionnaire to 259 students and found that the distribution of morning, intermediate and evening type did not differ from a normal distribution, with a ratio of 12-24-12. In contrast, Horne and Ostberg gave the questionnaire to 48 subjects and found a ratio of 18-10-20 and Ashkenazi *et al.* (1997) reported that true morning or evening types represented only 5-10% of a randomly sampled group. Kerkhof (1985) suggested that some of the ratio differences found in different studies could be due to socio-cultural differences between the groups sampled, due to the differences in mealtimes, language and hours of work etc.

One of the most prominent features of the difference in morning-evening types is that by definition they exhibit different timing for the pattern of sleep-wake. Furthermore, Breithaupt *et al.* (1978) report that morning types have less flexibility particularly in their rising times than evening types. When subjects were required to go to bed at 0100h and 0300h the morning type subjects responded by shortening their sleep length. In contrast, the evening types maintained a constant sleep length by adjusting their awakening time. It has been suggested that the differences in the flexibility of their sleep times are the result of differences in the dynamics of their temperature curves. Czeisler *et al.* (1980) and Zulley *et al.* (1981) have shown under conditions of internal desynchronisation the majority of awakenings coincide with the rising portion of the temperature curve.

Changes in the timing of sleep-wake and temperature may have implications for the sleep and adaptation of shiftworkers to altered schedules. For example morning-types may find it difficult to maintain alertness during the night shift, but easier to cope with early morning shifts.

In the following section the circadian rhythms of sleep and performance will be discussed in some detail. The rhythms of sleep and performance are perhaps the most important in regards to the problems experienced by shiftworkers. Following the section on the circadian rhythms of sleep and performance there will be a detailed discussion of the influence of shiftwork on these rhythms. In particular some of the complex interactions between sleep loss associated with shiftwork and the influence that this has on worker performance will be discussed. In addition, the influence of age on these rhythms and how this is influenced by shiftwork will also be considered.

Circadian Rhythm and Homeostatic Components of Sleep

Like many bodily functions sleep-wake behaviour displays a distinct circadian rhythm. Specifically there are circadian rhythms in both sleep propensity (ability to fall asleep) and in sleep duration (ability to maintain sleep) (Lavie *et al.*, 1981,1985,1986; Strogatz, 1986; Zulley *et al.*, 1981; Czeisler *et al.*, 1980). The sleep-wake rhythm is also influenced by homeostatic factors for example, prior hours of sleep and wakefulness (Åkerstedt and Gillberg, 1986; Webb and Agnew, 1971).

There appears to be a close link between the circadian rhythm of core temperature (CT) and sleep, such that sleep efficiency is maximal when sleep is initiated on the declining portion of the circadian rhythm of CT (Åkerstedt, 1984, 1985a, 1988; Moore-Ede, 1982, Wever, 1979). Under the entrained conditions of normal daily life, the most efficient sleep is typically initiated 5-6 hours prior to the temperature minimum. In contrast, non-adapted shiftworkers (when for example the rhythms of core temperature and melatonin maintain their normal phase position but sleep is during the day rather than at night) are typically attempting to sleep on the rising portion of the temperature rhythm and this results in shorter, less efficient sleep (Åkerstedt *et al.*, 1984, 1985b, 1988 Moore-Ede, 1982, Wever, 1979).

Sleep Propensity

Sleep propensity varies across the 24-hour day as a result of circadian rhythm and homeostatic processes (Borbely, 1982; Borbely *et al.*, 1992). Lavie and colleagues (1981, 1985, 1986) have illustrated the circadian variation of sleep propensity on several occasions. Using multiple sleep opportunities (in which subjects are asked to try and sleep for 7 minutes every twenty minutes, while the other 13 minutes are spent awake) across the 24 hour day and plotting the amount of sleep obtained in each trial they were able to calculate a sleep propensity curve. From these studies it was shown that the period of highest sleep propensity was from midnight to 0700 hours, with a less prominent peak of sleep propensity in the middle of the afternoon between 1300-1500 hours (post-lunch dip). The period of lowest sleep propensity was during the early evening (1800-1900 hours) and has been termed the forbidden zone for sleep. Lack and Lushington (1996) also reported a distinct 24-hour rhythm in sleep propensity and a significant 12-hour rhythm in 8 of their 14 subjects.

Less frequent sampling methods using the Multiple Sleep Latency Test (MSLT) have also shown fluctuations in sleep propensity across the day (Richardson *et al.*, 1978, Carskadon and Dement, 1977). Sugerman and Walsh (1989), reported that sleep propensity increased across the night using various measures of sleepiness including MSLT, Repeated Test of Sustained Wakefulness and Maintenance of Wakefulness Test (for a review of this area see Lavie, 1992).

Evidence from several studies under constant environmental conditions when subjects are free-running suggested that direct and/or indirect measures of sleep propensity were associated with the circadian rhythm of core temperature (Mills *et al.*, 1974; Czeisler *et al.*, 1980; Aschoff and Wever, 1981; Strogatz, 1986a). Strogatz (1986a) analysed the frequency of sleep onsets relative to the time of the body temperature minimum during free-running studies on 15 desynchronised subjects. When subjects are desynchronised there are differences in the period of overt rhythms. For example the overt core temperature rhythm would run with a period of about 25 hours and the overt sleep-wake rhythm would run with a deviating period ranging from approximately 12-65 hours (Wever, 1985). The times of most frequently occurring sleep were around the temperature minimum with a secondary peak approximately 10 hours after the minimum. There were also two periods during which few sleeps were initiated, 8 hours prior to the temperature minimum and 6 hours after the minimum, which where termed the "wake maintenance zones". This latter period of low sleep propensity coincides with a "wake up zone" during which subjects who have been asleep were most likely to awaken (Zulley *et al.*, 1981; Strogatz, 1986b). The "wake maintenance zone" will be discussed further in the following section on sleep duration.

Bes *et al.* (1996) investigated the variation of sleep propensity and REM and SWS propensity using a 2 nap protocol and found like researchers before them that REM and SWS propensity vary across the 24 hour day, and that they also have different time courses. REM sleep propensity exhibits a circadian modulation, while SWS propensity is linked primarily to the duration of prior wakefulness (Weitzman *et al.*, 1974; Carskadon and Dement, 1975)

Perhaps the most important aspect of the circadian rhythm in sleep propensity in relation to the current issue of shiftwork is that under monotonous environmental conditions there is an increased ability to fall asleep at night in normally entrained individuals. This can be seen as a consistent reporting of increased sleepiness at night, which has often been associated with, reduced performance and even actual short periods of sleep (Åkerstedt, 1988; Åkerstedt, 1995b; Gillberg, 1994). It is clear from the studies discussed above that under differing experimental conditions, the peaks and troughs of sleep propensity occur at similar clock time in entrained individuals lending support to the existence of a circadian rhythm in sleep propensity. Dijk *et al.* (1994) even suggested that the circadian rhythm of sleep propensity serves to consolidate sleep-wake.

Sleep Duration

Even though individuals are able to initiate sleep at sub optimal phase positions of the circadian cycle, at these times it is difficult to maintain sleep for 7-9 hours (Åkerstedt *et al.* 1981a, 1983; Åkerstedt, 1983; Campbell, 1984; Gillberg and Åkerstedt, 1982; Czeisler *et al.*, 1980; Wever, 1979). Shiftworkers may be able to initiate sleep in the morning following a night shift but are unable to maintain that sleep beyond midday (Foret and Lantin, 1972).

Czeisler *et al.* (1980) reported that sleep duration in a group of internally desynchronised subjects under free running conditions was shortest (~8 hours) when it began at or just after the mid trough of the temperature cycle and was longest (~14 hours) when subjects chose to start sleep at the temperature cycle maximum. The relationship between temperature and sleep duration persisted even when the hours of prior wakefulness exceeded 20 hours, supporting the suggestion that this is a circadian rather than a homeostatic function. Czeisler *et al.* (1980) also showed that subjects had a greater frequency of going to bed just after the temperature cycle minimum.

Similar results have been reported by Åkerstedt and Gillberg (1981a) and Gillberg and Åkerstedt (1982) using a different experimental paradigm. Åkerstedt and Gillberg (1981a) experimentally displaced sleep to seven different times-of-day and showed that sleep duration varied significantly. Maximum sleep durations occurred after evening bedtimes and the minimum sleep durations after morning/noon bedtimes. They suggested that these pre-selected sleep times reflect the circadian rhythm of sleep duration found in the *ad libitum* desynchronised isolation studies (Czeisler *et al.*, 1978; Zulley *et al.*, 1979). There was also a strong relationship between the core body temperature rhythm and sleep termination, such that subjects were more likely to awaken on the rising portion of the core temperature rhythm (Gillberg *et al.*, 1982). From this and other studies noon emerges as a period of sleep termination (Foret and Lantin, 1972; Czeisler *et al.*, 1978). Even when hours of prior wake increase, if sleep is postponed until between 2300-1100 hours sleep duration decreases. Åkerstedt and Gillberg (1981a) also suggested that this is clearly a circadian effect and closely related to the core temperature rhythm (see above) (Czeisler *et al.*, 1980). The results of these studies suggest that a disturbed sleep environment is not necessarily required for sleep durations to be reduced. Environmental factors for example, light, noise and temperature have often been blamed for disturbed day-time sleep of shiftworkers but it appears that circadian factors may be the primary reason.

In contrast to those studies that report reduced sleep durations due to time-of-day, some laboratory studies that invert the sleep-wake cycle have reported day-time sleep durations similar to those for night-time sleep periods (Weitzman *et al.*, 1970; Webb and Agnew, 1978). Åkerstedt and Gillberg (1981) contended that this may be related in part to age-related factors as subjects in many of these studies were aged between 18-25 years, while in their study subjects were aged between 29-45 years. The later age group are more representative of the range of most shiftworkers. Research indicates that the sleep of older individuals is poorer than their younger counterparts, and this will be discussed in more detail later. There are also studies of shiftworkers that report longer day-time compared to night–time sleep periods (Parkes, 1994; Budnick *et al.*, 1994). This may be because in both of these studies individuals were working 12-hour shifts and that at least in the Parkes (1994) study individuals were in an environment that partially reduced the influence of social and environmental factors.

Homeostatic Component of Sleep-Wake

Sleep is influenced not only by a circadian component (SCN), but also homeostatic factors. Individuals are able to postpone sleep, but not avoid it completely. After even one night of sleep deprivation individuals can experience periods of micro sleep (Kecklund *et al.*, 1993; Torsvall *et al.*, 1987; 1989). It could be suggested that this may be the body's homeostatic need for sleep coming to the fore.

As prior hours of wakefulness increase there is a corresponding increase in sleep duration (Webb and Agnew, 1975) and with increasing hours of prior sleep, that sleep duration decreases (Åkerstedt, 1986). Not only is the duration of sleep effected but there are also changes in sleep architecture. EEG studies reveal that the amount of slow-wave sleep increases with increasing duration of prior wakefulness (Webb and Agnew, 1971). In contrast, Campbell and Zulley (1989) showed that there was no relationship between hours of prior wakefulness and measures of slow-wave sleep. They suggest that their findings support the hypothesised 12-hour rhythm in the occurrence of slow-wave sleep and the influence of the circadian rhythm in sleep.

To investigate the homeostatic component of sleep while minimising circadian influences Åkerstedt and Gillberg (1986) studied sleep loss across 4 different conditions (0, 2, 4 and 8 hours of sleep) and then measured the effects on subsequent day sleep begun at 1100 hours. They found that sleep duration decreased as prior sleep length increased. While studies that have allowed spontaneous awakening, indicate that sleep deprivation of all or most of night sleep increased sleep duration by 10-25 %. From this finding Åkerstedt and Gillberg (1986) concluded that homeostatic influences play an important part in influencing sleep duration.

External factors for example light exposure have also been show to influence sleep duration. Dijk *et al.* (1987) reported that light exposure in the morning between 0600-0900 hours advanced wake up time for sleep on the following night relative to a dim light condition and that sleep duration was shorter for the light compared to the dim light condition.

From the studies discussed above it is clear that in combination circadian rhythms and homeostatic influences serve to control sleep-wake behaviour. As a result of these findings models have been suggested to calculate alertness and sleep propensity.

Models of Sleepiness and Alertness

There are several models that attempt to explain the influence of circadian and homeostatic components of sleep and wakefulness. These models of alertness and performance were initially developed from mathematical models of sleep propensity and regulation. A two process model initially proposed by Borbely (1982) included a homeostatic (prior sleep and wakefulness) and a circadian component. The circadian component was represented by a single sinusoid, and the homeostatic component rose in a saturating exponential manner during sleep and decayed exponentially during wake. In this model both components are combined in an additive manner to predict sleep duration as a function of sleep onset time. This model was then expanded by Daan et al. (1984) to include an upper and lower threshold, so that the model was able to predict the timing of sleep onset as well as sleep duration. Later another model was developed by Folkard and Åkerstedt (1991) and Åkerstedt and Folkard (1995) which stated that alertness is predicted by three things, a circadian factor (C), time since awakening (S), and sleep onset (S'), and a wake process (sleep inertia) (*W*). Subsequently Acherman and Borbely (1994) proposed a similar three process model, which modified the *W* component so that it included both a sleep inertia and 'wake inertia', reflecting the time it takes to fall asleep. This three process model has been reported to predict duration of sleep (Akerstedt and Folkard, 1996), sleep latency (Akerstedt and Folkard, 1994), and the alpha power density of waking EEG recordings (Akerstedt and Folkard, 1994, 1995).

The application of these models is important to predict human ability to perform under unusual sleep/wake schedules like those found in shiftwork and following transmeridian travel. Chapters six and seven in this thesis, while not predicting alertness do, illustrate the strength of the influence of the circadian component on the sleep/wake pattern of shiftworkers on irregular schedules.

There are many other models based on the above components and researchers are continuing to refine, expand and validate these in an attempt to accurately predict alertness under differing conditions. However, discussion of these models is not within the scope of this thesis (for further discussion of these models please see Borbely and Achermann, 1992).

As mentioned previously circadian rhythms are significantly altered with increasing age and this has a significant effect on the ability to initiate and maintain sleep. In the following section the differences in sleep between older and younger individuals will be discussed.

Individual Factors Influencing Sleep

Age

There are several studies reporting the differences in the sleep between older (>60 years) and younger subjects (~ 20 years) (Bliwise, 1993; Miles and Dement, 1980; Prinz, 1995). There is a significant difference in both the duration and composition of sleep between older and younger individuals. Sleep of older individuals occurs earlier, is shorter, lighter and more fragmented than the sleep of younger individuals. This is seen as earlier sleep onsets, longer periods in bed but less time asleep, longer wake after sleep onset, more stage 1 sleep and less stage 2, 3, and 4 sleep in older subjects compared to younger subjects (Williams *et al.*, 1974; Tune, 1969a; Miles and Dement, 1980). These age-related changes in sleep may be the result of changes in the circadian timing system of older individuals manifested as an attenuation of the amplitude, advance in phase and shortening of the period of circadian rhythms (Haimov *et al.*, 1994; Czeisler *et al.*, 1992; Myers and Badia, 1995).

While there is evidence of significant differences in the sleep of younger and older subjects there is much less literature on the changes to sleep between the ages of 20-59 years (Williams *et al.*, 1974; Tune, 1969a; Ehlers *et al.*, 1989; Carrier *et al.*, 1997; Reyner *et al.*, 1995). Carrier *et al.*, (1997) investigated the sleep of 110 subjects between 20-59 years of age and showed that with increasing age there was an earlier habitual bedtime and waketime and less time spent in bed at night. She also suggested that increasing age was associated with being more morning-type. The 20-59 year old range is of particular interest in the current thesis, as shiftworkers are not typically older than 60 (although the number of shiftworkers in this age group is increasing) or younger than 20 years of age (Australian Bureau of Statistics, 1993; 1997).

Like the circadian rhythm in sleep there is also a distinct circadian rhythm in performance. The reduction in performance at certain times of day and the corresponding increase in sleepiness due to sleep loss may contribute to shiftwork-related accidents or reductions in efficiency and productivity. For this reason it is important to have a clear understanding of the circadian rhythm of performance.

Circadian Rhythm of Performance

The circadian variations of numerous performance measures are well documented (Mott *et al.*, 1965, Folkard and Monk, 1980; Folkard *et al.*, 1985a,b; Colquhoun 1971). With few exceptions the variation in the efficiency of cognitive and psychomotor performance across the 24 hour day parallels the circadian course of core temperature (Kleitman, 1963; Folkard *et al.*, 1986; Monk *et al.*, 1983). Specifically, temperature is typically low at night and higher during the day-time and performance on most tasks follows a similar pattern. The pattern may vary depending on the type of task. For example, factors such as memory, perceptual involvement and logical reasoning all influence the pattern of the circadian rhythm in cognitive-psychomotor performance. Performance on those tasks involving manual dexterity, simple recognition, and reaction time are typically poorest around the temperature minimum (0400-0600 hours) and peak around 1600-1800 hours (Kleitman, 1963; Monk *et al.*, 1983). In contrast, verbal reasoning seems to peak earlier in the circadian cycle (Monk *et al.*, 1984; Monk *et al.*, 1986). Folkard and colleagues have quite extensively researched the influence of memory load; they have reported that tasks with a high memory load peak during the night-time (Folkard and Monk, 1980). Furthermore, night work experiments using a broad spectrum of tests indicate that different performance measures adjust at different rates to phase shifts. Hughes and Folkard (1976) found that on the ninth and tenth consecutive night shift that subjects showed greater phase adjustment on cognitive tasks, than for body temperature and simple repetitive tasks. Similar results were reported by Monk *et al.* (1978) for a laboratory study of 21 consecutive night shifts, where more complex tasks had a faster phase adjustment.

Variations in performance may be influenced by subtle differences between the type of task, but they may also be influenced by the way in which a task is approached. For example, if speed of identification is assessed, the usual relationship with temperature holds, that is, subjects became faster over the course of the day. However, if accuracy of response is assessed then peak performance occurs several hours earlier (Craig *et al.*, 1985; Monk *et al.*, 1986).

Performance on most tasks tends to follow the circadian rhythm of core temperature. Kleitman found a strong relationship between core temperature and performance on mainly simple repetitive tasks and even suggested that you could infer performance from the core temperature rhythm (Kleitman, 1963). In contrast, while Kleitman suggested that there was a causal relationship between body temperature and performance Colquhoun (1971) was more conservative and emphasised only a parallelism between core temperature and performance.

In comparison, Monk *et al.* (1997) stated that "extreme caution in assertions regarding the mechanism by which circadian performance rhythms occur" is needed. Under constant routine conditions Monk *et al.* (1997) found that performance on all the tasks measured (including serial search, verbal reasoning and manual dexterity) showed significant variation over time of day, with a low point close to the trough in rectal temperature. This was in contrast to earlier work that found under nycthemeral conditions tasks with a high memory load do not seem to parallel the circadian rhythm in core temperature (Folkard, 1975; Hughes and Folkard, 1976). Nevertheless, under constant routine conditions, there is some parallelism between these tasks and core temperature (Monk *et al.*, 1997; Johnson *et al.*, 1992).

Like the reduction in sleep propensity in the afternoon there is evidence to suggest that there is a post lunch dip in vigilance and perception tasks rather than in cognitive ones (Craig *et al.*, 1981; Monk *et al.*, 1996). However, Monk *et al.* (1997) under constant routine conditions found a post-lunch dip in reasoning accuracy even when subjects had no lunch.

Performance is also influenced by homeostatic factors for example, prior hours of wakefulness (Webb and Levy, 1972; Dinges and Kribb, 1991) and prior hours of sleep (Carskadon and Roth, 1991). These homeostatic influences, are in part what lead to the reduction in performance seen in shiftwork (Tilley *et al.*, 1981). During shiftwork the duration of prior hours awake is often increased (Knauth *et al.*, 1981- see section on sleep deprivation this chapter) and prior hours of sleep are often decreased (Tepas *et al.*, 1990 – see section on sleep restriction this chapter).

Performance and Age

The performance of older individuals has been reported to be lower than younger individuals on many cognitive tasks (Davies *et al.*, 1992; Welford, 1962; Webb and Levy, 1972). In a study of the effects of sleep deprivation between older and younger subjects Webb and Levy (1972) found that the performance of older subjects (40-49 years) started off lower on some tasks than for the younger subjects. This made it difficult to determine the relative effect of sleep deprivation on the performance of older and younger subjects, but they concluded that older subjects were more acutely effected by sleep deprivation.

In addition to the physiological factors performance may be influenced by motivation levels, experience with computers and competitiveness. In some cases older subjects may have less experience with computerised testing procedures and also not be as motivated or competitive as younger individuals on these types of task.

Summary

Taken together the previous section defines circadian rhythms with particular emphasis given to the circadian rhythms of sleep and performance. It is clear that sleep and performance are both controlled by an endogenous pacemaker and homeostatic influences and that they vary across the 24-hour day, with increased sleep tendency and reduced performance during the night-time hours. It is also apparent that there are individual factors that influence the circadian rhythms of sleep and performance and that this may have implications for the overt rhythm that is measured.

In the following section the influence of circadian rhythms on adaptation to shiftwork and the consequences of shiftwork related disruption of rhythms on sleep and performance will be discussed. Individual factors that may further influence the sleep and performance of shiftworkers will also be addressed.

1.4 Shiftwork and Circadian Rhythms

The most commonly reported physical complaints of shiftworkers are sleep disruption (Rutenfranz *et al.*, 1985; Tilley *et al.*, 1981; Åkerstedt *et al.*, 1990), fatigue and reduced alertness, but the degree to which shiftworkers complain of these is highly variable (Åkerstedt and Torsvall, 1981; Lee, 1992; Barton *et al.*, 1993). Many of these problems are the result of insufficient adaptation of the circadian system to continually changing work schedules (Åkerstedt, 1984, 1985a,b, 1988; Folkard and Monk, 1985; Moore-Ede, *et al.*, 1982). In fact evidence suggests that the circadian rhythms of shiftworkers never adjust completely to the night shift (Knauth *et al.*, 1981; Dahlgren, 1981; Knauth and Rutenfranz, 1982; Åkerstedt, 1985b: Hildebrandt *et al.*, 1987; Czeisler *et al.*, 1990; Eastman, 1990). As a result of the strength of circadian rhythms, total adjustment or re-entrainment of rhythms to a shifted schedule will often take several days or even weeks (Athananssenas and Wolters, 1981; Wegman and Klein, 1985; Winget *et al.*, 1984). In most instances adjustment may occur only partially, usually approximately 1 hour per day or not at all (van Loon, 1963; Wever, 1979, 1980; Mills, 1976).

Zeitgebers (e.g. light and social cues) are important factors when considering adjustment to shiftwork. Light-dark exposure in shiftworkers and particularly night workers is altered or reversed, while many social time cues maintain their normal pattern (Walker, 1985; Eastman *et al.*, 1994). Therefore, while it is possible for shiftworkers to adapt to night work, the adjustment process is often subverted. For example, night shiftworkers typically initiate sleep during the day-light hours (Tepas *et al.*, 1993), which results in reduced overall exposure to light. Given that the light-dark cycle may be one of the strongest entraining stimuli (see Dijk *et al.*, 1995 for review), the reduction in overall exposure to light for night workers can reduce the entraining strength of the night shift environment, making it more difficult to rapidly adapt. Some researchers are even investigating the use of timed exposure to bright light to aid shiftworkers in adjusting to their schedules (Eastman *et al.*, 1994; Dawson *et al.*, 1991). Adaptation is further compromised by the conflicting behavioural cues provided by the social and family environment (Folkard *et al.*, 1978a; Walker *et al.*, 1985) as these typically maintain their normal diurnal pattern. It is also typical for workers to revert to their normal sleep-wake and leisure activity pattern on days off (Knauth *et al.*, 1980; Tepas *et al.*, 1990). It is in part, this mismatch between the light-dark and social time cues that may make it more difficult for shiftworkers to re-entrain to shiftwork schedules.

The mismatch between behaviour and the physiological rhythms of the body may result in many of the alertness, sleep and performance problems experienced by shiftworkers. Due to the strong circadian rhythms in performance and sleep-wake, the lack of or partial adaptation of these rhythms to shiftwork means that workers are often sleeping and performing at times of day that are not conducive for this type of activity. In the following sections the relationship between sleep-wake behaviour, performance and shiftwork will be discussed.

Age and Adaptation to Shiftwork

Adaptation to shiftwork is often more difficult or slower in individuals as they get older (Haider *et al.*, 1981; Harma *et al.*, 1994; Harma *et al.*, 1990; Matsumoto *et al.*, 1987; Walsh *et al.*, 1991). This is possibly due to a reduction in the amplitude and lability of circadian rhythms as people get older (Myers and Badia, 1995; Weitzman *et al.* 1992; Czeisler *et al.*, 1982). As a result of their reduced ability to adapt to shiftwork, older shiftworkers may experience a greater level of sleep disruption (Pavard *et al.*, 1982, Tepas *et al.*, 1993; Harma *et al.*, 1994; Foret *et al.*, 1981). Harma *et al.*, (1994) reported that older subjects (mean age 57 years) adapt more slowly than the younger subjects (mean age 24 years) to their eight hour night shifts and that sleep in the older group was worse than for the younger subjects. This was evident from the observation that sleep duration was reduced and time in bed was increased. The reduction in sleep and adaptation for older subjects may in turn lead to reductions in performance and alertness above those reported for younger subjects when working shiftwork.

In contrast, Ashkenazi *et al.* (1997) concluded that tolerance to shiftwork is not related to age, years of shiftwork, type of industry or type of rotation. In several studies involving approximately 100 shiftworkers it was not unusual to find shiftworkers approximately 55 years of age and with 35 years of shiftwork experience with excellent tolerance to shiftwork. Good tolerance to shiftwork was defined as good sleep, low fatigue scores and a low incidence of digestive troubles and high performance on a grip strength task (Reinberg *et al.*, 1988; Andlauer *et al.*, 1979; Reinberg *et al.*, 1978a, 1978b). It could be suggested that Ashkenazi and colleagues found that age had a minimal effect on shiftwork tolerance because they studied primarily "survivor populations", that is shiftworkers who successfully survived this type of work schedule.

These studies clearly highlight the need for further research into the influence of age on adaptation to shiftwork, as well as the influence of shiftwork on sleep and performance.

1.5 Shiftwork and Sleep

Sleep disruption is the most commonly reported complaint of shiftworkers (Åkerstedt, 1988; Åkerstedt and Gillberg, 1981b; Rutenfranz *et al.*, 1977). Typically this is seen as a reduction in the duration and quality of sleep, particularly for sleep following the night shift (Tepas *et al.*, 1981; Tepas *et al.*, 1990; Åkerstedt, 1984; Åkerstedt and Gillberg, 1981b; Frese *et al.*, 1984, Folkard and Barton, 1993b) and for sleep prior to early morning shifts (Folkard and Barton, 1993b; Åkerstedt *et al.*, 1991a; Kecklund *et al.*, 1997). This increased sleep disruption may be the result of several factors, including work schedule, circadian rhythms, homeostatic, environmental and social factors (Walker, 1985; Czeisler *et al.*, 1980; Frese *et al.*, 1984).

During night work adaptation or re-entrainment, the timing of the sleep and wakefulness no longer maintains its typical relationship with the circadian pacemaker (Tepas *et al.*, 1993). It is this desynchrony or change in the phase relationship between the rhythm of sleep and wake and the circadian pacemaker that is a major factor leading to disrupted sleep, reduced alertness and reduced performance levels of shiftworkers (Eastman *et al.*, 1994; Åkerstedt, 1995; Tilley *et al.*, 1982). This can be seen when most rhythms, for example core temperature maintain their relationship with the pacemaker and sleep-wake activity is altered. As mentioned earlier sleep is most easily initiated on the decreasing part of the core temperature rhythm (Åkerstedt, 1984: 1985a,b; Moore-Ede *et al.*, 1982; Wever, 1979). Changes to the timing of sleep-wake across the day may vary depending on the type of shiftwork. Tepas *et al.* (1981) report that different shift types (night, day and afternoon/evening) alter the pattern or timing of sleep, work, and off-time differently (see Figure 2). The figure below shows that for night shifts and afternoon/evening shifts, rather than sleeping prior to work then working followed by off time as is the case with day workers, the pattern and timing of sleep is altered so that they sleep directly after work.

The pattern of sleep-wake activity can also be modified by competing influences such as family and social commitments (Folkard *et al.*, 1978; Lee 1992; Walker 1985). It has been suggested that factors such as shiftwork experience may influence how shiftworkers cope with the resulting disruption and that this in turn may alter their ability to adapt to shiftwork. This has been a criticism of some studies using non-shiftworkers and also of studies that only measure the short-term effects (one week or schedule rotation) rather than the long-term effects following changes to shiftwork schedules. Sleep may also be influenced by shiftwork schedules in that the length of shift (Rosa, 1995) and speed of rotation (Knauth, 1995) affect the duration of time-off between shifts (Kurumanti *et al.*, 1994) and therefore the opportunity to sleep and complete the other activities of daily living.

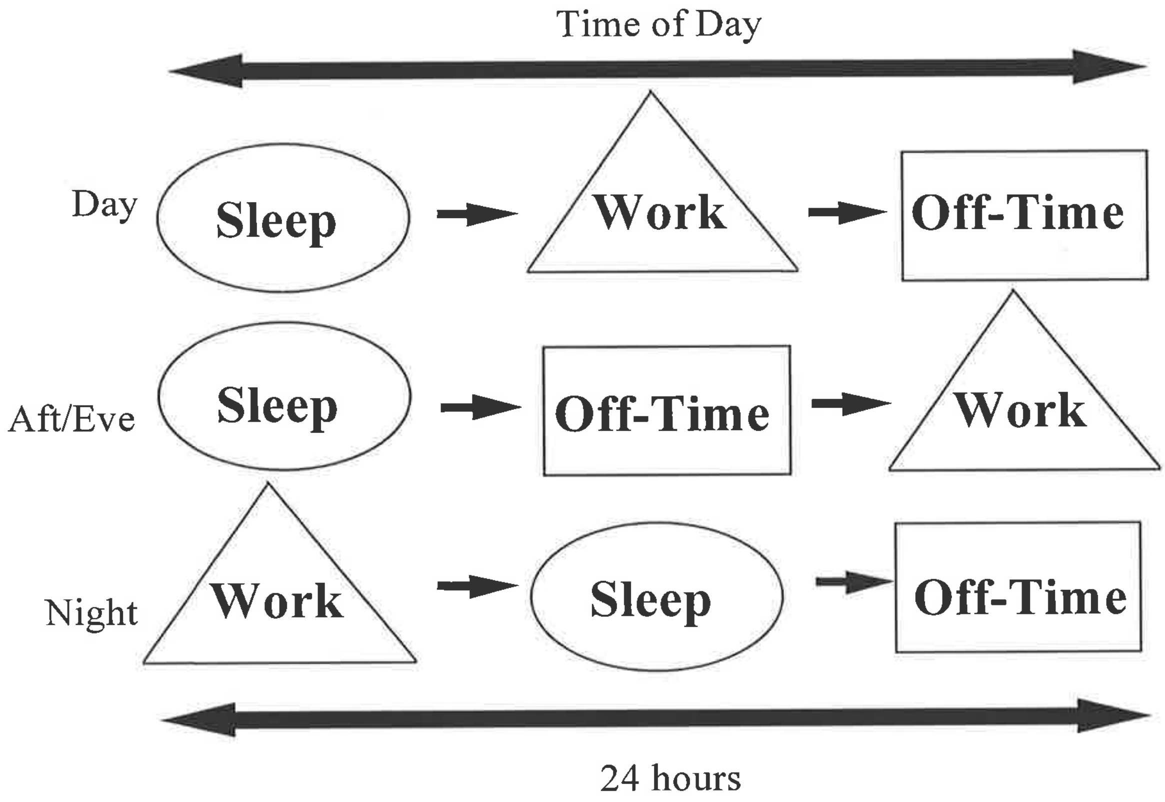

Figure 2. Model of typical work/sleep/off-time strategies used by shiftworers on day, afternoon/evening, and night shifts. (Tepas et al, 1993)

Sleep disruption is a major problem for shiftworkers and can result in significant reductions in performance and alertness (Tilley *et al.*, 1982; Harma *et al.*, 1994). In the following section I will discuss (1) methods of measuring sleep-wake activity including electrophysiological, actigraphic and sleep diary or questionnaire techniques (2) a variety of field and laboratory studies looking at the sleep-wake activity of shiftworkers.

Measuring Sleep-Wake Activity in Shiftworkers

The accurate measurement of sleep-wake activity in a shiftwork environment can be difficult. When dealing with volunteer subjects it is difficult to always get them to do exactly what you wish. Worksite studies may be further complicated by industrial or internal political (management and union) problems. Therefore, reducing the intrusion of the experimenter into the workplace and into the workers lifestyle is essential to allow collection of data from large numbers of subjects for extended periods of time. In an attempt to reduce experimenter contact and to increase participation, sleep diary or questionnaire techniques are often used, primarily due to their simplicity. However, there can be problems associated with this method of measurement, which will be discussed in some detail below.

There are also objective measures of sleep-wake activity that can be used including electrophysiological and actigraphic techniques. Although electrophysiological (EEG) procedures are widely accepted as the "gold standard" for measuring sleep-wake activity they are both invasive and expensive. As a result of this it can often be difficult to recruit subjects to participate in a field-based studies. Subjects may not only find it difficult to be restricted by the equipment involved in EEG recording but also easy access to the subjects may be difficult under some circumstances for example on aircraft or truck sleeping berths etc (although it has been achieved Mitler *et al.*, 1997; Kecklund *et al.*, 1993; Torsvall *et al.*, 1989). Although these types of logistical complications can be overcome they do involve greater researcher contact and interference in the normal day to day activities of the worker. This added contact may significantly alter the normal sleep/wake patterns of the worker.

A common alternative to electrophysiological measures of sleep wake is actigraphy (Tryon, 1991; Sadeh *et al.*, 1995). Due to the compact size of the instrument and ease of use, actigraphy is a popular alternative to EEG techniques of recording sleep wake activity. Actigraphy allows the experimenter to record activity levels for extended periods of time with little inconvenience to subjects. It has been suggested that actigraphy always be used in conjunction with a sleep diary to enable the detection of possible artifacts (Sadeh *et al.*, 1995).

Electrophysiological (EEG) Measures of Sleep

There have been several studies of shiftworkers using electrophysiological measures of sleep-wake activity. The technique can be used to determine sleep-wake activity in the laboratory (Kripke *et al.*, 1981) and in the field both at home and at work (Torsvall *et al.*, 1989; 1987; 1988 ; Åkerstedt *et al.*, 1991a; Mitler *et al.*, 1997). EEG can also provide a real time measure of sleepiness while on the job (Torsvall *et al.*, 1987) since increases in alpha and theta EEG activity are associated with increases in sleepiness (Torsvall *et al.*, 1985, Torsvall *et al.*, 1987). Some studies have reported that sleep episodes can occur at work, particularly during the later part of the night shift (Kecklund *et al.*, 1993; Torsvall *et al.*, 1989) and these sleep episodes may not be reported by the worker when sleep diary techniques are used because of their short duration. Electrophysiological techniques can also provide accurate measurement of the sleep quality of shiftworkers.

Although EEG is an extremely reliable measure of sleep-wake activity there are several problems with its use particularly in a field-based setting. In order to recruit subjects or maintain services, participants need to be willing to wear the electrode montage on their skull and face. In addition EEG recordings require considerable experimenter and subject interaction. Although most studies attempt to keep disruption of normal sleep-wake patterns to a minimum, subjects must designate their bed times so that the experimenter can be present to attach electrodes. This is a possible criticism of several EEG studies of shiftworker sleep that will be discussed in following sections.

Actigraphic Sleep Measurement

Actigraphy is an increasingly popular alternative to EEG for objectively measuring sleep-wake activity in shiftworkers and patient groups and has been shown to be highly correlated with electrophysiological measures of sleep-wake. The epoch for epoch agreement between electrophysiological and actigraphic sleep-wake scoring is between 78-96% (Sadeh *et al.*, 1989; Mullaney *et al.*, 1980). Similar correlations hold for measures of sleep efficiency r = 0.63-0.98 (Sadeh *et al.*, 1989; Kripke *et al.*, 1978) and sleep duration r = 0.82-0.97 (Mullaney *et al.*, 1980; Kripke *et al.*, 1978).

Although the correlation between nocturnal electrophysiological and activity measurement in both normal and patient populations have been examined (Kripke *et al.*, 1978; Mullaney *et al.*, 1980; Sadeh *et al.*, 1989, Cole *et al.*, 1992), actigraphy has not been validated in shiftworking populations. Since shiftworkers often sleep during the day as well as at night and there are differences in sleep characteristics at these times (Åkerstedt, 1995; Czeisler *et al.*, 1980; Tilley *et al.*, 1982), it is important to examine the day- and night-time correlation of actigraphy and electrophysiological techniques.

There is some evidence to suggest that the correlation between actigraphy and EEG is lower in older subjects (Mullaney *et al.*, 1980). This may be the result of age related changes in activity levels (Lieberman *et al.*, 1989) or more disrupted sleep of older individuals (Miles and Dement, 1980; Webb and Campbell, 1980). The epoch for epoch match has also been reported to be lower for sleep periods less than 390 minutes (Mullaney *et al.*, 1980). The sleep of shiftworkers and older individuals is often this duration or shorter, meaning that the accuracy of actigraphy in these groups may also be lower. This is supported by Levine *et al.* (1986) who states that as the likelihood of sleep decreases so does the accuracy of actigraphy in detecting sleep.

In a real-world (field-based) setting other factors may affect the usefulness of activity monitors. For example, the activity monitor is extremely sensitive and movements from a bed partner or vehicle movements may be recorded as wakefulness when the subject is actually asleep (Pankhurst and Horne, 1994).

Several studies have reported actigraphically recorded sleep-wake activity in shiftworkers (Walsh *et al.*, 1991; Tzischinsky *et al.*, 1990; Lavie *et al.*; 1992a; Buck *et al.*, 1989; Dawson *et al.*, 1995). Typically these studies utilised algorithms that were developed in patient or normal populations, even though the sleep wake activity of shiftworkers in many cases is far from normal.

The sleep quality of a shiftworker may depend upon when the sleep period occurs. If a shiftworker is sleeping at night their sleep may be quite normal, whereas if they are sleeping during the day there may be significant reductions in sleep quality. In fact the day-time sleep of shiftworkers has often been likened to the nocturnal sleep of older individuals (Åkerstedt, 1985). Another problem is that napping is difficult to factor into current algorithms. There is a need for an algorithm that is specifically designed for use in shiftwork settings. One more disadvantage to actigraphy compared to EEG techniques is that specific sleep stage information is not available and although a movement index may provide some indication of sleep efficiency it is not as detailed as EEG and has not been validated in a shiftwork setting as an adequate measure of sleep quality.

Sleep Diary or Retrospective Questionnaire

Although self-reported sleep diary techniques are valid they do not allow the researcher to objectively determine sleep duration and quality and rely instead on the subject determining when and how long they slept. Shiftworkers often become so acclimatised to the shiftwork lifestyle that they do not remember what their sleep patterns were like before commencing shiftwork (Spelten *et al.*, 1993) and therefore underestimate the impact it is having on their lives.

Another problem that may arise with sleep diary techniques is that the ability of individuals to estimate time asleep varies as a function of time-of-day. Åkerstedt and Gillberg (1981b) found that subjects constantly over estimated the length of day sleep, while other estimates of sleep length did not differ from EEG. Lushington and Lack (1993) found that subjects underestimate by a greater amount the duration of sleep before the sleep gate than after. Self-reports of sleep length may also vary depending on the instructions given. When sleep length was computed by asking when subjects fell asleep and woke up during work week, Tepas *et al.* (1981) showed this measure to be highly correlated (r = 0.83) with laboratory polysomnographic measures of total sleep time. Tepas *et al.* (1990) showed that simply asking workers how long they sleep, provides sleep duration estimates that have minimal or no correlation with polysomnographic techniques.

In the following section I will discuss a number of studies that report the sleep of shiftworkers using a variety of techniques from different industries and schedule types. It is apparent from these studies that there is a striking continuity in the type of complaints and the timing of when the shortest and poorest sleep occurs. Primarily shiftworkers have trouble obtaining adequate sleep prior to early morning shifts and after night shifts (Frese *et al.*, 1984; Åkerstedt *et al.*, 1981b; Folkard *et al.*, 1993b; Kecklund *et al.*, 1997).

Sleep of shiftworkers

Daytime sleep in non-adapted shiftworkers is usually terminated prematurely, is often reported as less satisfying and is significantly more fragmented. (Åkerstedt, 1984, 1985a,b, 1988; Knauth *et al.*, 1980; Moore-Ede 1982; Wever, 1979). This is a consequence of the temporal displacement of sleep relative to the circadian cycle and results in an average sleep duration of night shiftworkers that is approximately 2-4h shorter than that of normally entrained age-matched individuals sleeping during the night (Knauth *et al.* 1980; Åkerstedt *et al.*, 1983; Aannossen, 1964, Tepas *et al.*, 1981, 1982).

Like the laboratory studies that report shorter sleep durations when sleep is initiated during the day-time (Czeisler *et al.*, 1980; Zulley *et al.*, 1981; Åkerstedt and Gillberg, 1981a), there are laboratory and field-based shiftwork studies that report similar reductions in sleep duration when sleep onsets occur during the day-time (Kogi, 1985; Foret *et al.*, 1972). Kogi (1985) found that shiftworkers slept the most when sleep started at approximately 2100 hours, and slept for shorter periods if sleep was initiated after 0100 hours and slept the least if sleep started in the afternoon. Foret and Lantin (1972) found that in their study of train drivers on irregular shift schedules that they typically woke around noon following a night shift. These two studies lend support to the suggestion that this phenomenon is primarily a circadian influence on sleep and that irregular work schedules and other environmental factors such as day-time noise levels may have little impact. Evidence from laboratory studies in which environmental factors are controlled (Foret *et al.*, 1972; Czeisler *et al.*, 1980) confirm this conclusion. Nevertheless, further research in this area is warranted since several field-based studies have reported longer day-time sleep compared to night-time sleep (Parkes, 1994; Budnick *et al.*, 1994).

As a result of the homeostatic influence on sleep-wake not only is it important where in the circadian cycle that sleep is taken, but also the duration of prior hours of wakefulness and prior sleep. A 5 hour sleep at 1200 hours following a night shift, would be reduced to 3.5 hours if there was a 2 hour nap taken during the night shift, or alternatively to only 2 hours if a full night sleep was allowed prior (Åkerstedt and Gillberg, 1986) see figure 3 for schematic representation.

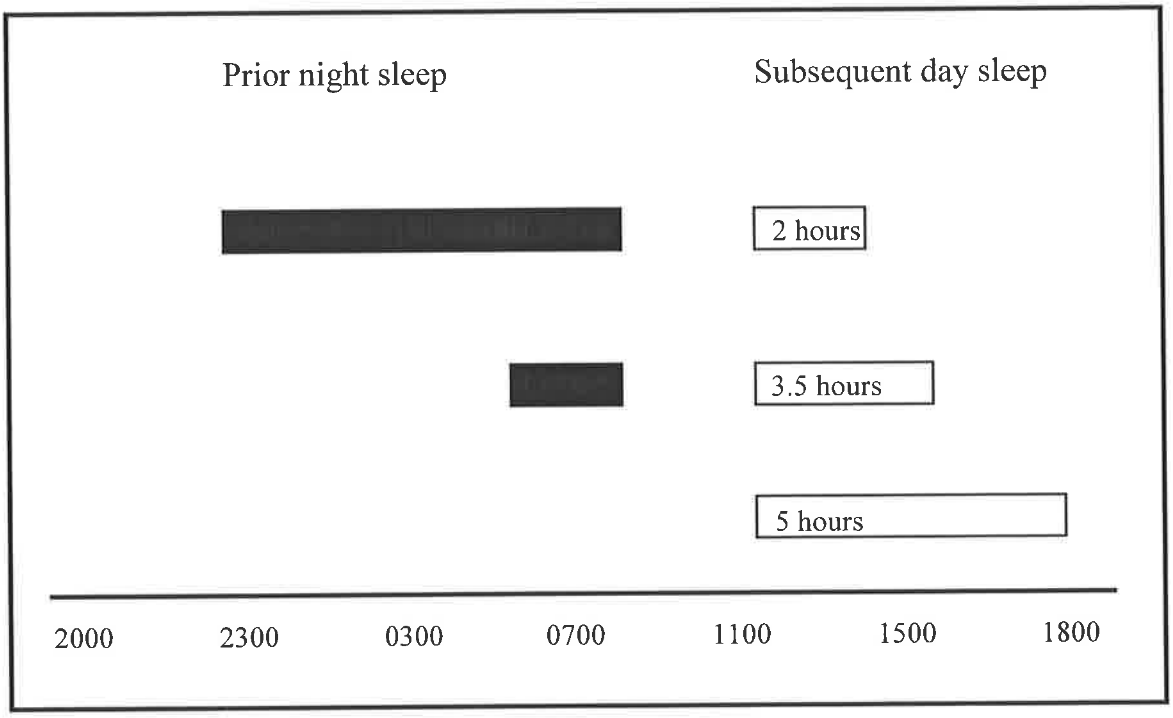

Figure 3. Schematic representation of sleep duration at 1100 hours following 8, 2 and 0 hours of prior sleep (Drawn from data presented by Åkerstedt and Gillberg 1986)

The duration of prior hours of wakefulness may vary depending on the type of shift schedule and where in the cycle of that schedule a worker is sleeping. For example there is often 24 hours awake prior to the first night shift in a sequence (Knauth and Rutenfranz, 1981; Glenville and Wilkinson, 1979). In contrast, prior to the sleep following the second night shift there may be only 12 hours prior wakefulness depending also on the duration of the break between shifts. The shorter day-time sleep periods may also further increase prior hours awake when compared to hours awake prior to a day-time shift.

There are a variety of studies that report similar findings, for survey, actigraphy, and electrophysiological methods both in the home and in the laboratory. In the following section I will discuss a number of these studies and the possible problems associated with them.

Field-based Studies of Shiftworker Sleep

Survey

There have been many survey studies of shiftworkers carried out in the past. A few of the larger studies will be discussed in relation to the type of survey technique used. Åkerstedt and Gillberg (1981b) surveyed 2000 individuals from various industries working either traditional 3, 8-hour shifts or an irregular schedule about the sleep disturbance associated with that schedule. There were modest differences between groups, but sleep following the night shift was always associated with the most disturbances. When the sleep disturbance reported in this survey study was compared with EEG recorded sleep at home and in the laboratory, sleep length was comparable between the laboratory and field for all three groups. Day-time sleep following night work was approximately 3.5 hours shorter than night-time sleep following day work. They suggested that the sleep disturbance experienced by these shiftworkers was the result of circadian rather than environmental factors, as it occurred both in the laboratory (environment controlled) and the field (environment not controlled).

Frese and Harwich (1984) surveyed 5448 shiftworkers and non-shiftworkers and reported the effect of shift type on sleep duration before and after work. Like other studies they reported that sleep following night shift was the shortest and that there was no significant difference between night and early morning shifts. There were no significant differences between 8 and 12-hour day and night shifts. In this survey both shiftworkers and non-shiftworkers had the same amount of sleep most likely because the shiftworkers compensated on days off for the sleep loss during the night and morning shift periods. Although sleep durations were similar the standard deviations were different, ranging from 1.35 hours in the non-shiftworkers to 1.88 hours for 12-

hour shift schedule with night work. The length of sleep and sleep quality were not highly correlated. Although this was a comprehensive study it may not have been the best way to accurately determine sleep duration and quality. One criticism of this questionnaire study is that they asked participants their average sleep duration but for the analyses used information about "how much sleep did you have yesterday". Another criticism is that the number of workers varied considerably between groups. As discussed earlier Tepas *et al.* (1990) found that this type of questioning has no significant correlation with EEG measures of sleep. A good point about this study, however, was that the sleep of shiftworkers was compared to that of non-shiftworkers.

Using sleep diary techniques in which subjects filled out a diary every day for 8 consecutive days, Knauth and Rutenfranz (1981) studied the sleep of 1230 shiftworkers. They showed that the shortest night-time sleep was before the morning shift (mean 7 hours). There was a large variation in the duration of day-time sleep depending on how it was classified. For example, sleep duration varied depending on whether it occurred before the first night shift (mean 2.1 hours), between two night shifts (mean 6.1 hours) or after the last night shift (mean 4.2 hours). They suggested that to minimise the accumulation of a sleep deficit it is best to limit the number of consecutive night shifts and to avoid starting the morning shift too early.

There are numerous other survey type studies that report the sleep-wake activity of shiftworkers (for example, Folkard and Barton, 1993b; Lee, 1992; Smith and Folkard, 1993, Sanquist *et al.*, 1997). Folkard and Barton (1993b) conducted a comprehensive survey study for 297 rotating shiftworkers from various industries. They found that sleep duration was shortest between consecutive night shifts but that it was also shorter between consecutive morning shifts compared to afternoon shifts. Lee (1992) studied 760 nurses (permanent, night, evening, day workers and rotating workers) and reported greater sleep disturbance for those nurses on night and rotating shifts. Smith and Folkard (1993) studied 124 personnel from a nuclear power plant and like many other studies showed that sleep duration and quality were most profoundly effected following a night shift.

Some researchers have investigated other factors that might influence the sleep of shiftworkers. Tepas and Mahan (1989) found that sleep was reduced following night shift even in experienced night workers who preferred night work. Mahan *et al.* (1990) separated 1078 workers on either a permanent 8-hour day or night shift into those with complaints of sleep disturbance and those without. The sleep duration of night workers was shorter than that for day workers regardless of whether they reported sleep difficulties or not. This lead to the conclusion that the reduction in the sleep of night workers was a result of a sleep deficit rather than sleep disturbance.

EEG Studies of Shiftworker Sleep

There have been a number of laboratory and field-based studies that have used electrophysiological (EEG) techniques for determining sleep-wake activity. Dahlgren (1981) studied six experienced rotating day-night shift and six experienced permanent night shiftworkers, recording self-selected sleep and wake times using EEG for a total of six sleep periods in the laboratory. For the permanent night shiftworkers, day-time sleep periods were 1-2 hours shorter ($p<0.05$) than for night-time sleep periods. In contrast, the rotating shiftworkers had their shortest sleep period on the first day-time sleep period. There were also significant changes to sleep architecture; all stages except SWS were altered for the day-time sleep periods of the rotating shiftworkers and sleep duration and sleep changes were greater at the beginning of the week. Overall the permanent night shiftworkers adapted biologically better to the night shift than the rotating shiftworkers. One of the weaknesses of this study was that the three sleep periods were not evenly spaced across the work week; one was following the first night shift and the other two were at the end of the work week. There may have been changes in the sleep episodes that were not recorded in the intervening period.

Problems may occur when conducting shiftwork studies that combine field and laboratory (Kripke *et al.* 1981). This study by Kripke *et al.* (1981) involved EEG recordings in the laboratory for a group of male night workers who were asked to indicate their preferred sleep times and then confine sleep periods to these times. Subjects who had irregular sleep periods were excluded. Kripke and colleagues (1981) experienced trouble with this method and data was not collected from all subjects for 4 consecutive days as planned. This was primarily because subjects did not sleep during the times they had specified and so the most disrupted sleep periods were missed. Nevertheless for those subjects for whom there was data they had a short day sleep of approximately 6 hours 25 minutes (compared to normal sleep duration of 7-8 hours, Tune, 1969a,b). However, on the days prior to coming into the laboratory and on days missed, laboratory subjects slept only 4 hours and 24 minutes, 2 hours less than when in the laboratory. What this study does clearly show, however, is that there must be factors other than circadian ones influencing when these workers chose to sleep. Indeed Kripke *et al.* (1981) reported that their subjects had other social and domestic commitments that resulted in the days missed in laboratory.

There are many types of shift schedule and particularly in the transport sector irregular schedules are popular. Due to the erratic nature of the schedule it might be expected that sleep-wake patterns would be more adversely effected than for other schedules. In a study by Foret and Lantin (1972) of ten French train drivers (mean age of 41.5 years) on an irregular shift schedule EEG were recorded in the home and in dormitories. Similar results to those recorded in laboratory studies looking at the circadian rhythm of sleep duration were found (Czeisler *et al.*, 1980). Sleep duration varied as a function of the time-of-day that sleep was initiated. The longest sleep was recorded when sleep was initiated between 2300-0200 hours. In contrast, between approximately 0300-2000 hours sleep was shorter with the shortest duration if sleep was initiated between 0900-1000 hours. Perhaps the most important point to be taken from this study is that drivers woke up around noon whatever time they went to bed following a night shift.

Walsh *et al.* (1981) carried out a comprehensive study of 30 shiftworkers who maintained their normal work schedule but slept in the laboratory. There were 10 workers in each of 3 groups, including day workers, nightworkers and rotating shiftworkers (afternoon/evening shift). To take into account, at least in part, the influence of shiftwork experience they only included subjects who had at least 1 year of experience. Sleep was recorded in the laboratory for 4 consecutive sleep periods during the workweek. Like many other shiftwork studies this study revealed that day sleep following the night shift was shorter than for the day and rotating shiftworkers, however, the sleep of rotating shiftworkers was studied only when on day and afternoon/evening shifts. Night workers also had a greater percentage of SWS than other groups and significantly less time in stage 1 and REM sleep. Walsh *et al.* (1981) suggested that night shiftworkers experience chronic sleep deprivation and may accrue a considerable sleep debt across the work schedule as the sleep of the night workers was similar to that of people undergoing partial sleep deprivation (Mullaney *et al.*, 1977; Webb and Agnew, 1974).

A weakness of this type of study is that making the subjects come into the laboratory or recording sleep by EEG at home may itself influence sleep. Although studies usually attempt to reduce the impact of experimenter involvement, they still need to attach electrodes and some interference is inevitable. If sleep is delayed in the morning after night shift then workers may find that they may have less sleep before they reach the 'wake up' zone around midday and therefore sleep is reduced more than if they just had to go home and get into bed.

In contrast to the study described above by Walsh and colleagues (1981), Tilley *et al.* (1981) studied EEG recorded sleep in the home for six male rotating shiftworkers for a complete roster cycle. Although sleep was measured in the home, Tilley *et al.* (1981) reported similar findings to those reported by Walsh *et al.* (1981). Specifically, the duration of sleep for the night shift and morning shift were reduced compared to the afternoon shift and day-time sleep periods were 25% shorter than night-time sleep periods. Daytime sleep contained more stage 0,1 and REM sleep and the timing of sleep stages was altered in the day-time sleep periods. They suggested that these results represent a reduction in sleep quality for day-time sleep as well as a reduction in sleep duration. When more subjects (12) were observed in the same protocol similar results were reported (Tilley *et al.*, 1982).

As an alternative to measuring sleep only during specific sleep periods, Torsvall *et al.* (1989) carried out a study in which they measured EEG continuously for 24 hours. This study ensured that all sleep episodes during the day were recorded including naps and microsleeps. The study was carried out on twenty five male rotating shiftworkers (night and afternoon shift). Sleep following the night shift was 2 hours shorter than sleep following the afternoon shift. Unlike some other studies of EEG recorded sleep they also showed that 20% of the workers had sleep episodes during the night shift and that 28% of the night shiftworkers took an afternoon nap. This means that although other studies may be able to accurately determine main sleep periods and some naps, they may be underestimating the amount of sleep that shiftworkers obtain across the day.

Studies of shiftworkers consistently show that sleep during the day-time is significantly reduced. There are several studies reporting that the duration of sleep for shiftworkers on early morning shifts is shorter than prior to shifts that started later in the morning, despite both groups sleeping at night (Åkerstedt *et al.*, 1991a; Tilley *et al.*, 1982; Folkard and Barton, 1993b). Kecklund *et al.* (1997) conducted a study using a control group to specifically look at early morning work and its effects on sleep. Twenty-two female subjects with either an early morning 0630 hour start (mean age 40.6 years) or a 0830 hour start (control group mean age 33.3 years) had EEG recordings of their sleep at home. To reduce interference with spontaneous bed times, subjects were wired up 2 hours before their normal bed time and the experimenter left the subjects residence at least one hour before bed time to allow subjects to retire spontaneously. Early morning work reduced sleep by almost two hours and involved less stage 2 and REM sleep. Kecklund *et al.* (1997) suggested that the reduced sleep duration was the result of subjects on the early shift not sufficiently compensating for the 3 hour advance in rising time compared to a control group as subjects only went to bed approximately one hour earlier than they normally would if they were not working the next day. In a similar study Bjerner *et al.* (1948) reported that when changes were made to shift start times from a 0400 to a 0600 hour start there were significant increases in sleep duration prior to the morning shift. It is interesting that a two hour change in schedule only results in a 45 minute increase in sleep duration. This may be the result of sleep onset times being determined by a combination of circadian and psycho-social factors.

It has also been suggested that shiftworkers may be apprehensive about being able to wake up on time prior to an early morning shift, because of the difficulty in terminating sleep at the circadian trough (Åkerstedt *et al.*, 1993; Dinges, 1989). Other studies also report apprehension of over sleeping as a factor in sleep disruption. For example, in a study of five ship engineers "on call", EEG sleep was recorded in the field for "on call" nights (Torsvall *et al.* 1988). Sleep durations for these men during the night were shorter (1.6 hours less) and contained less SWS and REM sleep, compared to a free night sleep. The authors suggested that this reduction in sleep may have reflected apprehension about being woken by the alarm.

Other than the timing of the shift, there are additional factors that may influence the sleep of shiftworkers including the time off between consecutive shifts (Kurumanti *et al.*, 1994), shift duration (Rosa, 1993) and the direction and speed of rotation (for a review see Knauth, 1995). These factors influence both when a worker can sleep and how long they have available to sleep. Kurumanti *et al.* (1994) demonstrated that there was a high correlation between the length of free time between shifts and sleep duration (r=0.95). From their study of rotating shiftworkers they concluded that at least sixteen hours off between shifts was required to obtain a sleep duration of 7-8 hours. It has also been shown that shiftworkers may have significant differences in sleep durations for a similar break duration between shifts depending on the time of the break. For example, Mackie and Miller (1978) reported that drivers obtained 6.5-7 hours of sleep on a regular daytime schedule, but that drivers with start times of 0300 hours averaged 5.5 hours and for a 2000 hour start only 4 hours sleep. This was in spite of drivers being afforded the opportunity to sleep for 8 hours. However this relationship between the timing and duration of breaks and subsequent sleep has not been clearly demonstrated and neither has the influence of extended work hours. When the duration of shift is extended there is the possibility that individuals will not be able to obtain 'adequate' sleep, as the duration between shifts is generally shortened, for example from 16 hours for most 8-hour shifts, to 12 hours for shifts of 12-hours. When increased fatigue from an extended work day, reduced opportunity to sleep and the limited time to carry out the responsibilities of daily living are combined there may be significant increases in sleep loss above those already reported for 8 hour shifts. This may be even greater for those individuals such as doctors and truck drivers who work even longer hours or irregular hours.

Extended Work Hours and Sleep

12-hour shift schedules are popular in many industries, particularly where access to the work place is difficult (e.g. in the mining industry). However, there is some concern but no consensus about the degree of sleep disruption associated with 12-hour shifts. The majority of 12-hour shiftwork studies have reported significant reductions in day-time sleep duration (Rosa, 1991; Frese *et al.*, 1984; Foret and Lantin, 1972; Tilley *et al.*, 1981; Torsvall *et al.*, 1981, 1989; Parkes, 1994), however, there are several studies that have shown significantly lower sleep durations during the night compared to the day-time (Budnick *et al.*, 1994; Gillberg, 1997; Rosa *et al.*, 1993; Parkes, 1994). Budnick *et al.* (1994) reported that sleep durations (sleep diary) for the day shifts were on average 5.6 hours compared to between 6-6.6 hours for the first three night shifts. By contrast the average sleep duration following the final night shift sleep was only 5.2 hours when on a 4 days on, 4 days off, 4 nights on schedule. Similarly Anderson and Bremer (1987), reported that on a DDNN schedule sleep following the second night shift was shorter than following the first night shift. It is important to point out that although the day-time sleep durations were longer than the night-time sleep durations they were all typically shorter than a normal (7-8 hour) night sleep. This may be the result of several factors including shortened time off between consecutive shifts compared to 8-hour schedules as workers have to compress the activities of daily living, including sleep into a shorter period. Alternatively Budnick *et al.* (1994) suggest as do other researchers (Folkard and Barton, 1993b; Kecklund *et al.*, 1997), that the reduction in sleep prior to a 0600 hour start may result from workers not significantly altering bed times due to both circadian and psycho-social factors and apprehension of waking. Therefore, this is an issue of the timing of the shift rather than simply the duration, as a similar pattern of sleep is reported for early morning shifts that are 8-hours in duration.

Comparison of 8 and 12-hour shift schedules by Tucker *et al.* (1996) demonstrated that there were no significant differences in sleep durations. In contrast, Peacock *et al.* (1983) reported that the sleep habits on a 12-hour schedule (DDNN) were better than for an 8-hour shift schedule. They concluded that a satisfactory day sleep can occur following the first night shift and that while the first night sleep in the roster was 8.5 hours long, the sleep durations for night 2 and day1 and 2 were not different.

Rosa and colleagues have completed a number of studies investigating the influence of 12-hour shifts on sleep and performance (Rosa *et al.*, 1993; 1989; 1988; Rosa, 1991). Some studies have compared 8 and 12-hour shifts and others have investigated the same group of shiftworkers over several months or years to determine whether experience of a shift schedule influences sleep or performance. In a comparison of 8 and 12-hr shifts Rosa *et al.* (1993) found that there was no significant difference between total sleep time for day and night shifts. There were, however, consistent reductions in total sleep time across the workweek, particularly on the 12-hour night shifts. In an earlier study, Rosa *et al.* (1989) reported that there was 40 minutes more sleep on the night shift compared to day shift and that total sleep time was reduced over the work week for both the old 8-hour and the new 12-hour schedule. The workers in this study reported that after 7 months on the new 12-hour schedule that they slept satisfactorily but often complained that their sleep was too short. They also reported that they sacrificed sleep to participate in non-work activities, which was reflected in later bed times under the new 12-hour schedule at night while day-time bed time remained the same. A follow up study 3.5 years later at the same site by Rosa (1991) reported shortened total sleep time after night shift, suggesting that workers did not learn to adapt to the new schedule.

Even for shifts of longer duration, drivers working 13-hour night shifts had an average day sleep duration of 4.4 hours, which was 40-85 minutes shorter than for drivers on similar day-time or rotating schedules (Wylie *et al.* 1997). The sleep of workers on 12-hour shifts thus appears to be altered in a similar way to shifts of a shorter duration and in some cases worse than eight-hour shifts.

Cumulative Sleep Debt and Shiftwork

With the significant reductions (1-4 hours) in sleep duration following night shifts and prior to early morning work, a quite substantial cumulative sleep debt can be accrued across the work week (Javanis and Kaneko, 1990; Tilley *et al.*, 1981; Tepas, 1982; Tepas *et al.*, 1989). This accumulated sleep debt may exacerbate the circadian performance impairment observed at night and be reflected in a reduction in performance across the workweek (Tilley *et al.*, 1981). As mentioned previously, performance is influenced by many factors including circadian, homeostatic (prior hours awake and sleep), environmental (light, noise, temperature) and psycho-social (motivation, stress) factors. Performance on many tasks is at a low point at night anyway and when sleep loss (either partial or extended) is added to this, performance can be reduced further.

Studies that look directly at performance following sleep restriction are reported later under the heading of sleep deprivation as the influence of sleep loss in shiftworkers has often been inferred from sleep deprivation or sleep restriction studies.

Composition of Shiftworkers Sleep

As mentioned in the section of the circadian rhythm of sleep there are fluctuations in the composition of sleep across the day (REM) and depending on the hours of prior wakefulness (SWS) (Webb and Agnew, 1971; Weitzman *et al.*, 1974; Carskadon and Dement, 1975). This means that the composition of shiftworkers sleep is also altered, as sleep time and prior hours of wake are also altered. As a result the sleep of shiftworkers during the day is more interrupted and altered in its ultradian stage sequencing compared to a night sleep (shorter REM latency, less stage 2, different distribution of REM), which may mean that it is less restorative (Tepas *et al.*, 1990; Åkerstedt, 1985b; Colquhoun *et al.*, 1996). For this reason there has been some debate about whether the restorative value of sleep is a function of its duration or composition. Some research suggests that total sleep time (TST) rather than sleep stages are more important for recovery or maintenance of waking performance (Johnson *et al.*, 1974; Lubin *et al.* 1974). This will be discussed later when discussing the influence of sleep restriction on performance.

Individual Differences Influencing the Sleep of Shiftworkers

There are factors other than shift schedule that may influence the amount of sleep obtained by shiftworkers. As mentioned previously, shorter sleep durations have been associated with increasing age particularly above the age of 40 years (Tepas *et al.*, 1993; Åkerstedt *et al.*, 1981b). There is also a negative relationship between years of shiftwork experience and sleep (Foret *et al.*, 1981).

Age and Shiftworker Sleep

As the average age of the population in western industrialised countries increases so to does the average age of the workforce (US Bureau of Census, 1991; Australian Bureau of Statistics; 1993). For example, in Australia over the past four years the number of shiftworkers has increased and specifically the number of those above the age of 60 years has increased by 50% (Australian Bureau of Statistics, 1993, 1997) (see Table 1). This may have serious implications for shiftworker health and safety as many researchers have shown that there are significant differences in the ability of older subjects to adjust to disruptions to circadian rhythms like those caused by shiftwork (Harma *et al.*, 1994; Harma *et al.*, 1990; Matsumoto *et al.*, 1987; Walsh *et al.*, 1991; Costa *et al.*, 1989). There are also significant differences in sleep and performance as people get older, that are unrelated to the effects of shiftwork (Williams, 1974; Tune, 1969a; Miles and Dement, 1980; Webb and Levy, 1972).

Table 1. Indicates the number of Australian shiftworkers in each age category for the census year 1993 and 1997. ('000)

Age	1993	1997
15-34	463.1	482.6
35-44	231.8	272.7
45-54	140.7	173.7
55-59	30.3	37.7
60 and over	10.5	15.2

Numerous studies both in the field and the laboratory have reported significant reductions in the sleep duration and quality of older shiftworkers above those reported for younger shiftworkers (Foret *et al.*, 1981; Parkes, 1994; Tepas *et al.*, 1993; Åkerstedt *et al.*, 1981b; Pavard *et al.*, 1982; Mitler, 1998; Lee, 1992). Åkerstedt and Torsvall (1981) concluded that age is a major predictor of sleep length. In particular there appears to be a reduction in tolerance (especially for sleep) to shiftwork for those over the age of 40 years (Tepas *et al.*, 1993; Costa *et al.*, 1989).

In a questionnaire study of 747 subjects from an oil refinery, Foret *et al.* (1981) investigated sleep quality for 4 different age groups in shiftworkers, non-shiftworkers and former shiftworkers. They found that age and years of shiftwork experience significantly affected subjective sleep quality. Poor sleep quality in the younger subjects < 29 years was due to trouble falling asleep while in the older subjects >40 years poor sleep quality was associated with more night-time or early morning awakenings. This is similar to the increase in early morning awakenings of older individuals reported by Webb and Campbell (1980). In addition, extended shiftwork experience had a negative effect on sleep quality.

Tepas and colleagues (1993) studied the sleep and nap length in a group of 2988 workers between 18-59 years of age. They found that self-reported sleep length was significantly influenced by age. However, age did not have a significant influence on napping behaviour. Similarly, Pavard *et al.* (1982) reported that sleep length decreased with age, with the largest difference for night shiftworkers. Night shiftworkers aged 20-30 had a sleep length 1.5 hours longer than night workers over the age of 50. The same has been shown for 12-hour shiftworkers where age was found to be negatively related to sleep quality and duration (Parkes, 1994).

Psycho-social Factors

In addition to physiological factors there are many social and domestic factors that influence how much and when a shiftworker chooses to sleep. Sleep may be curtailed to enable shiftworkers to have meals with their family, attend school or other social functions and sporting commitments. Shiftworkers usually have more to their lives than work and sleep. By having to juggle work, sleep and other commitments shiftworkers may experience significant stress that can lead to increased absenteeism and health problems (Harrington *et al.*, 1978; Monk *et al.*, 1992). The stress that shiftwork can place on family life is reflected by a higher divorce rate for shiftworkers than day workers (Tepas, 1985; Knutsson *et al.*, 1986). By identifying factors that influence the sleep, health and stress levels of shiftworkers it may be possible to reduce the influence they have on lives.

In a study by Folkard *et al.* (1978) of full time and part time night nurses the full time workers slept more during their time off in comparison to the part time nurses. There were also more nurses with children in the part time group than in the full time workers. Folkard *et al.* (1978) concluded that the full time nurses had a greater commitment to their job and therefore sleep more, whereas the part-time nurses had a greater commitment to things other than work.

Gender

Like the increase in the average age of shiftworkers there is also an increase in the number of women employed in professions that involve shiftwork. In Australia over the past four years there has been an increase in the number of shiftworkers of just over one hundred thousand; the majority of those were women (Australian Bureau of Statistics, 1993; 1997).

Women have much more difficulty in coping with shiftwork than their male counterparts. Often as a result of having to both run a household and maintain a job, women take less time to sleep in favour of these other activities (Gadbois, 1981; Wedderburn, 1990). This means that in some cases female shiftworkers are sleeping considerably less than male shiftworkers (Oginska *et al.*, 1993).

Summary

Taken together, it is clear from the studies discussed above that the sleep duration and quality of shiftworkers is significantly reduced particularly following night work (Tepas *et al.*, 1989; Tepas *et al.*, 1981; Tepas *et al.*, 1990; Åkerstedt, 1984; Åkerstedt *et al.*, 1981b; Frese *et al.*, 1984; Folkard *et al.*, 1993b) and prior to early morning shifts (Folkard *et al.*, 1993b; Åkerstedt *et al.*, 1991a; Kecklund *et al.*, 1997). This is believed to be a result of a combination of circadian, homeostatic, environmental and psycho-social factors (Walker, 1985; Czeisler *et al.*, 1980; Lavie, 1986; Tepas *et al.*, 1993). Scheduling factors other than the time of the shift may influence the amount and timing of sleep, for example the duration of shifts, breaks between consecutive shifts and the direction and speed of rotation (Kurumanti *et al.*, 1994; Tepas *et al.*, 1989; Knauth, 1995).

The significant reductions in the sleep of shiftworkers may have serious implications for worker health and safety (Knutsson *et al.*, 1986, Mitler *et al.*, 1988). Sleep loss has been associated with significant reductions in alertness and performance both on and off the job (Tilley *et al.*, 1981; Totterdell *et al.*, 1995). Considering that on many types of shiftwork schedule workers may be loosing the equivalent of one night of sleep each week, performance could be reduced quite significantly. In the following sections the influence of shiftwork and sleep loss or deprivation on performance will be discussed.

1.6 Shiftwork and Performance

The circadian mal-adaptation that results from shiftwork schedules may significantly influence performance. Shiftworkers are often working at a time (night-time) in the circadian cycle that is not conducive to good performance (Colquhoun, 1971; Mott *et al.*, 1965; Kleitman, 1965). When the circadian low of performance is combined with sleep disruptions and the resulting sleep loss associated with shiftwork, performance may be reduced further (Tilley *et al.*, 1981).

There are serious implications for shiftwork related performance impairment. Several of this century's major industrial accidents have occurred in the early hours of the morning on the night shift, for example, the Chernobyl, Three Mile Island and Exxon Valdez disasters (Mitler *et al.*, 1988; Ehret, 1981). The cost of these accidents in monetary, social and environmental terms is staggering (Leger, 1994; Webb, 1995; Mitler *et al.*, 1988). Most shiftwork related accidents are not as spectacular as these are but they have still been estimated to cost industry and the community billions of dollars each year worldwide (Webb, 1995). It is perhaps for these reasons that the influence of shiftwork on performance has become an increasingly important area of research.

Determining the effects of shiftwork on performance is not a simple task. On the job performance may be influenced by many factors including tiredness/sleepiness/fatigue, mood (angry, aggressive, nonchalant behaviour), environmental factors (noise, temperature, motivation) and circadian factors (Folkard and Monk, 1979; Costa, 1997).

In the following section a conceptual model by Folkard and Monk (1979) that describes and summarises many of the factors that influence "on shift" performance will be presented. Also different measures of shiftworker performance will be discussed. These include real task studies of worker performance across the day, simulated shiftwork studies in the laboratory, field-based studies using laboratory type tasks and a few studies that combine measurement of sleep and performance in both the laboratory and field.

Conceptual Model of Shiftworker Performance

Folkard and Monk (1979) propose a conceptual model encompassing the factors that they believe either do or probably influence "on shift" performance (see Figure 4).

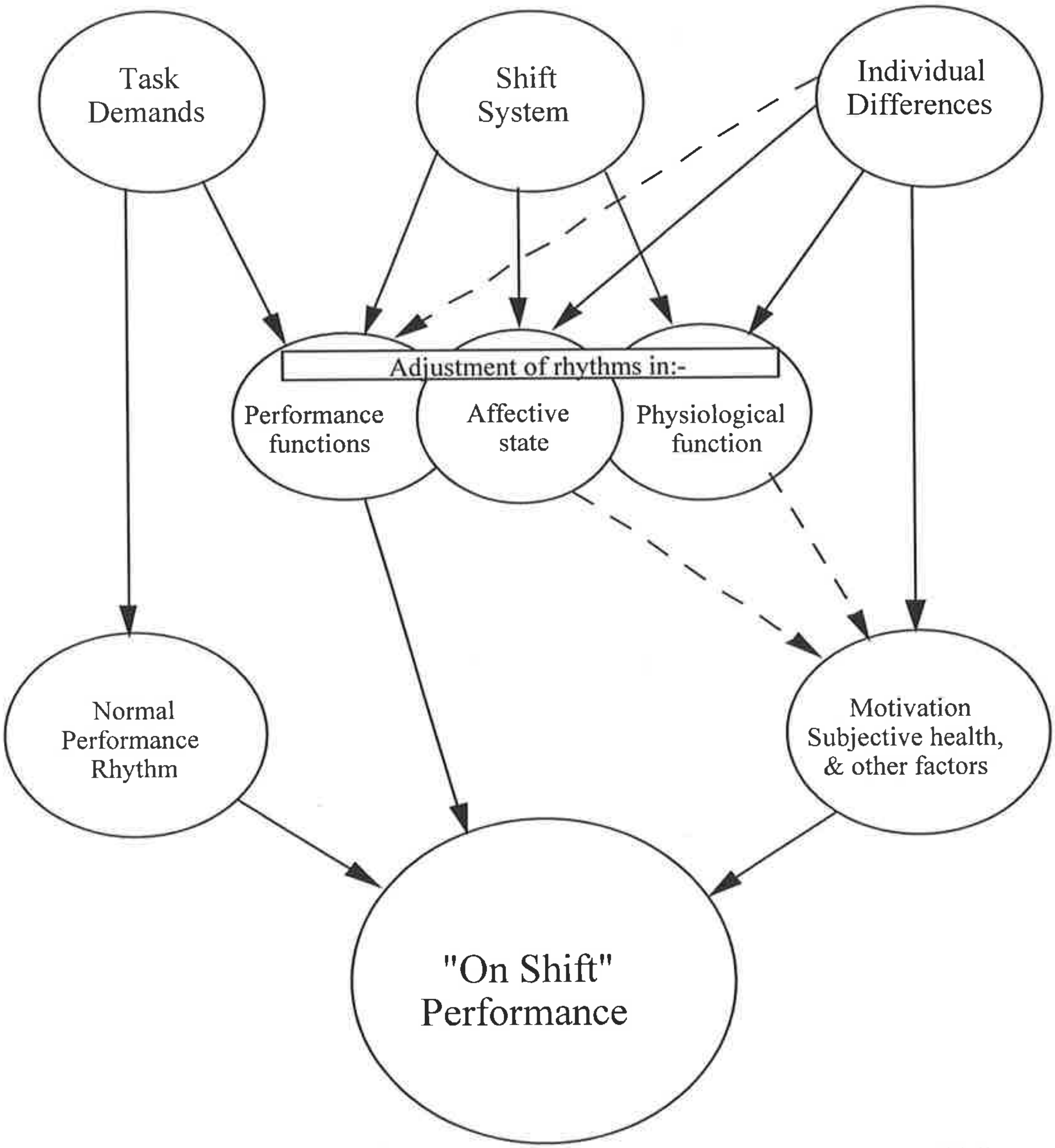

Figure 4. A conceptual model of the factors affecting 'on shift' performance. Solid lines represent known influences and dashed lines probable ones (Folkard and Monk, 1979)

As stated previously, determining the effects of shiftwork on worker performance, productivity and safety is a difficult and complex task. According to Folkard and Monk (1979), on the job performance is not only affected by the type of task performed but by time-of-day, sleep deprivation and loss, subjective and objective health affects, motivation, social and domestic factors and individual factors and the rate of adaptation of these factors to the disruption caused by shiftwork. They suggest that the three major factors influencing worker performance are the type of task, shift system and individual differences. As an example, the suggestion that night shift performance will be poor because workers are performing at a time of day that is not conducive for good performance is too simple. For some tasks performance is better at night and other factors for example, age and motivation may be more important than circadian influences alone.

Measuring Shiftworker Performance

Measuring performance accurately in either the laboratory or in the field can be difficult. There are many factors that influence performance, for example, motivation (Khaleque and Verhaegen 1981), learning or practice effects, lighting, noise, temperature, time-of-day, prior hours awake and prior hours of sleep (Folkard and Monk, 1979). All of these factors need to be taken into account and possibly controlled for in some way when investigating performance.

Under laboratory conditions these factors are somewhat easier to control than when testing in a field-based setting. If these variables are removed in a shiftwork setting it may not be possible to obtain a true picture of worker performance or fatigue levels. For example, if the shiftworkers are normally performing in a factory under hot and noisy conditions, their performance may change if these factors are removed. Due to the complex nature of the factors affecting shiftworker performance it is often difficult to infer from one industry or work place to another. This means that to clearly look at the influence of a shiftwork schedule on performance it is ultimately necessary to test workers on the job despite the problems involved. There are several ways in which shiftworker performance can be measured, for example, real task measures, simulated laboratory testing and the use of laboratory type tests in the field.

Shiftworker real task performance can be measured in many ways. Worker productivity and efficiency (number and quality of products made), absenteeism and the number of accidents or near misses could all be analysed. There are many studies that report a significant increase in the risk of accident on the night shift (Wojtczak-Jaroszowa and Jarosz, 1987; Ong *et al.*, 1987; Novak *et al.*, 1990; Laundry and Lees, 1991; Shannon *et al.*, 1993).

Technological advances including automation have altered the type of work that many workers undertake. Rather than being directly involved in the operation of machinery, automation results in the worker having more of a monitoring or vigilance role, for example in nuclear power plants and aircraft. Vigilance performance, which is critical to the previously mentioned industries, is extremely sensitive to the effects of sleep loss and sleep deprivation and is reduced during the night-time (Dinges and Kribb, 1991; Colquhoun, 1971). There are advantages to the automation of tasks in that with simple modifications to equipment, changes in performance can be monitored by errors or number of misses, to determine when most incidents occur.

An alternative to field based measures of shiftworker performance is to simulate shiftwork in the laboratory and measure performance on laboratory type tasks, for example, vigilance, reaction time, memory or grammatical reasoning (Monk *et al.*, 1978; Folkard *et al.*, 1976; Wojtczak-Jaroszowa *et al.*, 1978; Tepas *et al.,* 1981). The laboratory is, however, a novel environment where factors like light, noise and temperature are controlled and this may result in underestimating the performance impairment associated with a particular roster schedule. Another weakness is that due to the expense of the studies, the number of schedules that can be investigated is limited. With the ever increasing number of shiftwork schedules that are arising everyday, determining the impact of all of them is practically impossible. There are, however, advantages in using laboratory studies because they allow the researcher to look at specific factors of the work schedule while removing external environmental and social factors that may influence performance.

A good alternative to the real task measures and simulated laboratory studies are studies that use laboratory type tasks that are sensitive to sleep loss and fatigue in a field-based setting. These studies resolve some of the problems related to real task measures as the testing is standardised for each shift and the influence of the work place is not removed. An advantage of this approach is that there is evidence that there is a difference between the subjects typically recruited for laboratory type studies and real-shiftworkers (e.g. years of shiftwork, age, coping strategies, health, social and environmental factors).

In the past, long monotonous tasks have been put forward as the best indicators of performance impairment during sleep loss (Dinges, 1992; Dinges and Kribb, 1991; Wilkinson, 1964, 1968). However, rather than having tests that are approximately an hour long, shorter tasks (3-10 minutes) have also been reported to be sensitive to sleep deprivation (Dinges, 1992; Dawson and Reid, 1997; Wojtczak-Jaroszow *et al.*, 1978). The use of longer tests limits the range and number of field-based measurements that can be taken before the procedure becomes too intrusive (Dinges, 1992). Differences in performance impairment recorded on both an hour and shorter 10 minute tasks may been seen as differences in the magnitude rather than the timing of impairment (Dinges, 1997).

Although using laboratory type tests in the field is often a viable option in determining shiftworker performance there may be problems in many work settings. The worker needs to be willing and able to take the time to do the tests and so it is essential that companies, unions and employees are supportive of the testing procedure. A problem with this type of testing is that they are often only conducted for short periods of time and learning effects and the novelty of testing, may compromise the findings. If the aim of the study is to measure the performance impairment associated with a new roster schedule, it may be necessary to run testing for longer periods of time, especially if there is some hostility to the roster change by the employees. In this case motivational and social factors may influence performance testing for short periods of time and a clear picture of the performance impairment may be reduced.

From an industry perspective, on the job performance may be the only aspect of performance that is of interest. However, on a community level, if a shiftworker is driving home tired after a long night shift the ability to drive the car may be impaired and an accident may occur. The effects of a shift system may have far reaching effects beyond performance and shiftworker lifestyle. There are a few studies that report shiftworker performance on recovery days (days off) and determine the time taken for a shiftworker to return to their optimal level of performance (Rosa *et al.*, 1988; Totterdell *et al.*, 1995) in an attempt to address this issue.

In the following section actual studies that measure various aspects of shiftworker performance will be discussed.

Studies of Shiftworker Performance

Real Task Measures

There are several real task studies commonly cited (Folkard and Monk, 1985). Although these studies involved different tasks, they all consistently showed reduced performance during the night-time. Some of these studies measured the speed (Browne, 1949; Wojtczak-Jaroszowa and Pawlowska-Skyba, 1967) or accuracy (Bjerner and Swensson, 1953) of a task while others measured the consequences of lapses in attention or vigilance (Prokop and Prokop, 1955; Hildebrandt *et al.*, 1974; Folkard *et al.* 1978).

What these studies clearly showed is that performance during the night-time was reduced compared to the day-time. As mentioned above there may be numerous reasons for night-time reductions in performance, other than circadian factors. There may be for example different work tasks allocated to the night-shift compared to those performed during the day-shift (Meers, 1975).

Performance During Laboratory Simulated Shiftwork

There are two main types of measures used to determine performance of shiftworkers in the laboratory; neurobehavioral tasks and simulator tasks (e.g. flying or driving). Studies that have simulated shiftwork schedules in the laboratory using student or real shiftworkers as subjects (Monk *et al.,* 1978; Folkard *et al.*, 1976; Wojtczak-Jaroszowa *et al.*, 1978; Tepas *et al.*, 1981) have consistently shown that performance is significantly reduced during the night compared to the day-time and that over a work week, performance is often further reduced (Tilley *et al.*, 1981). Often associated with these reductions in performance are reductions in sleep across the workweek and a decline in alertness (Tilley *et al.*, 1981).

Tepas *et al.* (1981) combined laboratory and real work conditions to measure the effect of shiftwork on sleep and performance. Prior to each sleep period subjects completed an hour-long battery of tests, and were then tested again after waking up. There were significant reductions of vigilance and addition tasks on the night shift compared to day and rotating (afternoon/evening) shiftworkers. It is important to note that the rotating workers were only studied for the day and afternoon/evening shift; if the study had included the night shift there may have been reductions in performance for this group compared to day workers reflecting the reduction in performance due to circadian rhythms. Tepas *et al.* (1981) concluded that the reductions in performance were primarily due to time-of-day effects, however, there was a low correlation between measures of sleep including total sleep time and minutes of REM sleep. One limitation of this study was that it was not clear how long after waking the performance tests were conducted; if they were done directly on waking there may have been some sleep inertia effects. Sleep inertia has been reported in studies of napping, in which subjects report feeling groggy and perform worse on tasks for up to 5-30 minutes upon awakening (Muzet *et al.*, 1995). The performance impairment observed for the night workers resembled the performance impairment observed for individuals undergoing partial sleep deprivation (Webb and Agnew, 1974; Mullaney *et al.*, 1977).

Using a test that simulated real tasks, Gillberg *et al.* (1996) compared day and night driving performance for nine professional truck drivers using a driving simulator. Driving performance was significantly reduced for the night driving compared to the day driving, however, the difference was small. Although there was a significant increase in sleepiness, there was not an equivalent decrease in performance and Gillberg *et al.* (1996) suggested that this might have been a result of driver and night work experience, such that the drivers experience compensated for the increased sleepiness.

Laboratory Type Tasks in the Field

A common alternative to laboratory studies are those that use laboratory type tasks in the field. In such a study Tilley *et al.* (1981) measured sleep at home (discussed above) and performance at work using a 4 choice serial reaction time and a simple reaction time task, both which have been shown to be sensitive to the effects of sleep loss (Glenville *et al.*, 1978). Performance on both tasks was reduced on the night shift compared to the afternoon shift. The authors suggested that the performance impairment on the night shift may not have been the result of shiftwork per se but an effect of time-of-day. However, performance appeared to be influenced by the significant cumulative sleep debt, as a result of the reduction in day-time sleep during the work week. This was seen as a reduction in performance on the night shift across the work week, such that simple reaction time on shift 3, 4 and 5 was significantly less than on shift 1 and 2. A limitation of this study was that performance was only measured once, approximately an hour prior to the end of the shift. It may have been better to test more frequently or at the least to have compared performance at both the beginning and at the end of the 12-hour night shift. This would have allowed a more complete picture of the effect on performance across the shift and at different times of day.

Dahlgren (1981) and Wilkinson *et al.* (1989) found that after a week of night shifts, simple but not choice reaction time tasks were reduced similar to the results reported by Tilley *et al.* (1981; 1982). From these studies they concluded that a week of night shifts appears to have the most detrimental effects on performance. When performance on shifts has been compared with respect to the direction of the rotation of the shift there is no good evidence to suggest that one direction is worse than the other, however, the consensus is that forward rotating does appear to be associated with fewer problems (review see Knauth, 1995).

Performance may be influenced by prior hours of wakefulness. Glenville (1979) measured the performance of 12 young (18-25 years') computer operators using portable reaction time tests. During this study performance was reduced on the night shift compared to the day particularly for the first night shift. The authors suggest that this may be a consequence of the extended hours of wakefulness prior to the first night shift. In previous studies, the workers similarly did not sleep during the day prior to this first night shift (Knauth *et al.*, 1981). Glenville *et al.*, (1979) also suggested that laboratory based-sleep deprivation studies may be able to provide a reasonable indication of what to expect in the field as similar hours of wakefulness produce comparable results both in the field and in the laboratory. Another salient point made by the authors was that although performance on this reaction time task was reduced, it could not be concluded that performance on the job would also have been reduced to a similar degree (e.g. driving performance in the Gillberg *et al.*, 1996 study). Nevertheless this type of study does provide relevant information on the type of performance impairment that occurs during shiftwork.

When performance and EEG were measured simultaneously there was a high prevalence of inattention and performance lapses on the night shift. Rosekind *et al.* (1994) observed lower performance on the night shift of long haul commercial airline staff, and Torsvall and Åkerstedt (1987) found similar results in self-ratings of sleepiness for locomotive drivers.

As previously mentioned it has been suggested that performance impairment may be best detected by long monotonous tasks. Wojtczak-Jaroszow and colleagues (1978), however, found that performance on the night shift was reduced compared to the morning or afternoon shifts using the presentation of three, 1-minute performance tests. Three factors were identified that influenced performance levels; time-of-day, time elapsed since beginning of shift and physical activity prior to testing. Some studies directly comparing shifts of different duration are discussed below.

Extended Hours of Work and Performance

Extended hours of work may have a significant impact on workers productivity, efficiency and performance. There are several situations in which workers may be required to work longer than the typical 8 hours per day, including over-time, rostered hours of work and on call rosters (for example those worked by resident physicians (review by Leung and Becker, 1992) and other emergency occupations (Todd *et al.*, 1989)), as well as the long hours worked in the transportation industry.

There is no real consensus with regard to the impact of 12-hour shifts on performance and sleep compared to 8-hour schedules. As a result of time-of-day effects on performance it is difficult to determine whether performance is reduced further for 12-hour shifts. Nevertheless, there have been several studies that have investigated the impact of 12-hour shift schedules on performance and others that compare performance on 8 and 12-hour schedules.

Rosa and colleagues have completed a number of studies both in the field and in the laboratory looking at the influence of 12-hour shifts on performance and sleep. Rosa *et al.* (1989) reported that reaction time and grammatical reasoning were decreased after 7 months on a 12-hour shift compared to the previous 8-hour schedule. One advantage of the 12-hour schedule was that the performance was maintained across the workweek. It was suggested that the shorter workweek compensated to some degree for the longer shifts. However, workers rarely took the performance battery more than once or twice per day, and there was also less test battery participation towards the end of the 8 hour week, which makes it difficult to compare between the two schedules, considering time-of-day as a factor.

A follow up study by Rosa (1991) 3.5 years after the first study showed that there were few improvements. Performance decreased across the shift with an increase in the errors reported at end of the 12-hour day shift compared to the 8-hour evening shift and at the end of night shift compared to the 8-hour night shift. The lowest performance was reported at the end of 12-hour night shift. These results suggested that performance on the 12-hour shift was worse than the 8-hour schedule, similar to that reported previously by Rosa *et al.* (1985) in a laboratory study.

Another laboratory study by Rosa and Colligan (1988) using a battery of tests showed an increase in data entry errors across the workday from 1730 hours onwards during 12-hour day shifts. There was also a speed and accuracy trade off towards the end of the shifts, in that reaction time remained the same but error rate increased. Rosa and Colligan (1988) suggested that the lack of or highly variable change in performance across the day was the sum of fatigue due to the extended work day and the improvement in performance due to time-of-day effects, but that fatigue effects were more critical than circadian influences at least in the day shift hours of the current study.

Duchon *et al.* (1994) compared performance on a 12-hour shift schedule following a change from an 8 hour rotating schedule in an underground mine under environmental and physically stressful work conditions. They reported that performance was improved on the 12-hour schedule compared to the 8-hour schedule. Due to possible practice effects improving performance on the 12-hour schedule they advised caution in interpreting these results as workers had completed the tasks more often by this time. Peacock *et al.* (1983) found significant decrements in performance in both 8 and 12-hour shifts, but no significant difference between shifts on critical flicker fusion or grammatical reasoning.

There have also been studies investigating the impact of extended hours of work on real task measures. Todd *et al.* (1989) reported that nursing care was adversely effected by 12-hour shifts, but that direct physical care was not impaired. In a study of truck drivers, Hamelin (1987) reported that the risk of an accident increased with hours at the wheel and the time-of-day that the drivers were at the wheel. Specifically, accident risk increased after 11 hours at the wheel especially at night, so that there appeared to be an interaction between time-of-day and extended hours of work. In a more recent study of driver performance using several different measures, Wylie *et al.* (1997) reported that the time-of-day that individuals were driving was more important than hours of work, in determining drowsiness and poor performance. They showed that night driving between 0000-0600 hours was associated with poorer performance on each of four important variables, including drowsiness, lane tracking, code substitution, and sleep length. The hours of driving and number of consecutive trips had minimal or no impact on these variables. From this study it was concluded that time-of-day was a better predictor of decreased driving performance than time on task or the cumulative number of trips.

Memory Load

Shiftwork studies have often been used to determine the relationship between time-of-day and performance on task with varying levels of memory load. As mentioned previously memory tasks may not parallel core temperature as is the case with other performance tasks (Folkard *et al.*, 1976; Monk *et al.*, 1978). These shiftwork studies suggested that performance on some tasks with differing memory load adapts more rapidly to night shifts than others. The studies have been briefly discussed in the section on circadian rhythms and performance but in this section they will be discussed in the context of shiftwork rather than purely circadian rhythms.

Folkard and Monk (1980) studied the retention of information from a training film in night nurses using both immediate and delayed recall tests. Those subjects who had poor adjustment to shiftwork had higher immediate recall at 0400 and 2030 hours, but the opposite situation was found for those workers who had good adjustment to their schedule. Immediate recall may adjust more quickly to night work and adjustment of circadian rhythms may not be useful in improving performance on some tasks.

Monk and Embrey (1981) studied six process controllers working 12-hour shifts and found a negative correlation between the circadian rhythm of performance on low and high memory tasks. Maury and Queinnec (1992) showed that for shiftworkers on a 3x8h roster that there was an evolution in phase opposition for recall according to whether the information was initially encoded on the basis of semantic or typographic characteristics. Later Maury and Queinnec (1993) reported that there was a significant time-of-day effect on recall such that at 1800 hours workers recalled more words at beginning of a list where as at 0200 hours they remembered more at end of the list.

Taken together these studies clearly show there is a significant influence on the adaptation of the test depending on the memory load of the performance test given, and that some tests may adapt faster than others to the disruption to circadian rhythms due to shiftwork.

The influence of the level of adaptation, shift duration, type of task, time-of-day and many other factors on shift performance has been investigated to some degree. However, one factor that has not been clearly investigated is the influence of age on shiftworker performance.

Age and Shiftworker Performance

There are few studies that directly compare the performance of younger and older subjects while working shiftwork schedule (de Zwart *et al.*, 1993). Rather it has been more common to compare the sleep and subjective alertness levels of older and younger workers (Pavard *et al.*, 1982; Tepas *et al.*, 1993; Foret *et al.*, 1981; Harma *et al.*, 1994). The few studies that have compared performance of older and younger subjects during shiftwork have shown that performance is generally lower in older subjects (de Zwart *et al.*, 1993).

To some degree the relationship between shiftworker performance and age has been inferred from studies of sleep deprivation or disruption that compare younger and older subjects, however, these studies have generally involved subjects who were between 60-80 years of age. Considering that most shiftworkers typically retired by 65, this group of subjects may have little relevance to older shiftworkers. In addition, since shiftworkers are rarely awake for more than 24 hours, studies using 60 or more hours of sleep deprivation have little relevance in a shiftwork setting.

Morning-Eveningness and Shiftworker Performance

In addition, in a group of Swedish day workers Torsvall and Åkerstedt (1980) report a negative correlation between morningness-eveningness and age, such that older age groups had a tendency towards morningness. In a study of morningness-eveningness in shiftworkers Patkai (1970) observed that in groups of 'morning workers' and 'evening workers' there was a significant interaction between diurnal type and time-of-day for self-rated alertness, performance on visual choice reaction task and oral temperature. Morning types had higher values in the morning than in the evening on all measures except for oral temperature and the opposite was reported for the evening types.

Summary

To summarise, research to date suggests that there are many factors that have a significant role in determining shiftworker performance, including time-of-day, prior hours of sleep and wakefulness, memory load and in some cases shift duration. The primary finding has been that performance at night is reduced on almost all tasks regardless of shift duration or rotation. This conclusion was supported by the decrease in real task measures (Browne, 1949; Wojtczak-Jaroszowa and Pawlowska-Skyba, 1967) and performance on laboratory type tasks at night (Tilley *et al.*, 1981; Glenville, 1979). There is still, however, no clear understanding of the influence of age or extended hours of work on shiftworker performance. From previous research it might be assumed that due to the increased sleep disruption and reduced adaptation to shiftwork of older subjects, their performance would be consistently worse, but this has not been clearly demonstrated.

As mentioned previously the impact of shiftwork on performance has often been inferred from sleep deprivation or restriction studies. Therefore, in the following section the influence of sleep deprivation, restriction and reduction on performance will be discussed.

1.7 Sleep Deprivation, Restriction and Performance

Although shiftworkers often experience sleep disruption they are rarely continually awake for periods greater than 24 hours (Australian Bureau of Statistics, 1993). Knauth and colleagues (1981) reported that approximately 50% of shiftworkers do not sleep during the day prior to a night shift. This suggests then that in many cases workers have woken at their normal time in the morning and then not slept again until the following morning after work. By the end of the shift the worker may well have been awake for 24 hours or more. A more common occurrence, however, is for shiftworkers to experience cumulative sleep debt over successive consecutive days/nights of a shift schedule (Tilley *et al.*, 1981; Javanis and Kaneko, 1990; Tepas *et al.*, 1989).

It is often assumed that fatigue related accidents only occur when workers actually fall asleep. What sleep deprivation studies clearly show, however, is that although there may be short periods of sleep associated with serious performance deficits, some performance decrements can occur without micro sleeps (Dinges and Kribb, 1991).

In the following section the effects of extended and partial sleep deprivation, sleep restriction of stages and their influence on performance of both older and younger subjects will be considered.

Continuous Sleep Deprivation and Performance

Sleep deprivation even for one night significantly disrupts mental and physical function (Dinges, 1992; Dinges and Kribbs, 1991). Sleep loss can alter many aspects of performance; slowing of reaction time, delaying of responses, failure to respond at the correct time, false responses, slowed thinking and diminished memory (Dinges *et al.* 1991; Johnson, 1982). Most aspects of human performance generally reach low levels at night, due not only to the influence of the circadian pace-maker, but also to loss of sleep or prior hours of wake (Aschoff *et al.*, 1972).

The extent of the performance decrement during sleep deprivation depends heavily on the type of task and its duration (Horne, 1985). During the first 1-2 days of sleep deprivation motivation to perform is primarily effected, rather than the inherent capacity to perform (Wilkinson, 1965; Naitoh, 1976; Johnson, 1982), as performance can be maintained or even improved with incentive (Horne *et al.*, 1985a).

The factors that influence the performance impairment measured during sleep deprivation are similar to those mentioned in the section on measuring shiftworker performance. There are task variables for example, task duration, knowledge of results, difficulty of task, task pacing, proficiency level (practice effects), task complexity and memory requirements and non-task factors that come under the headings of psychological and situation factors. Psychological factors can be interest level, motivation, personality or repeated experiences, while the situation factors are exercise, noise, temperature and drugs (Johnson, 1982).

Task duration and motivation have been shown to significantly affect the degree of performance impairment observed during sleep deprivation. Tasks that are longer and more monotonous like simple reaction time and vigilance tests have been shown to be very sensitive to sleep deprivation. If a task is replicated, with each successive replication, performance is decreased (Wilkinson, 1969). Wilkinson advocated the use of 30-60 minute vigilance tasks as sensitive indices of sleep loss (Wilkinson, 1968), however, tasks of 10-15 minutes are sufficient to reveal the effects of wakefulness beyond 18 hours. Some studies have even shown that tasks of as short as one minute are sensitive to sleep loss (Heselgrave and Angus 1985; Wojtczak-Jaroszowa *et al.*, 1978; Dawson and Reid, 1997).

The Lapse hypothesis has been proposed to explain the performance impairment observed under conditions of sleep deprivation. It is proposed that an increasing number of absences or pauses in subject response is the major behavioural consequence of sleep loss, rather than a reduction in accuracy. Between lapses, subjects may perform normally (Johnson, 1982). Lapses are defined as extremely long reaction times such that the subject fails to respond to the task in a timely manner. Williams *et al.* (1959), reported that during sleep deprivation there was an increase in the range of reaction times and that after 78 hours of sustained wakefulness mean reaction times and the number of lapses increased 4 and 18 times respectively.

There is no doubt that performance is reduced as a result of sleep deprivation, however, there are many factors that may influence the degree of impairment recorded, some of these have been discussed previously. While sleep deprivation increases subjective sleepiness and decreases performance it may be difficult to show to what extent the performance impairment in the field, for example that seen during shiftwork, is the result of purely sleep deprivation. Under laboratory conditions many of the factors that influence performance can be controlled and it is perhaps for this reason that sleep deprivation studies have often been used to infer levels of shiftworker performance. There is some support for this suggestion (Glenville, 1979; Tilley *et al.*, 1981).

Sleep Restriction and Performance

Shiftworkers commonly experience partial and cumulative sleep deprivation as a result of reductions in day-time sleep of 1-2 hours (Frese *et al.*, 1984; Tepas *et al.*, 1981). There are few if any shiftwork studies that have directly investigated the influence of sleep of various lengths (partial sleep deprivation) on performance. There are, however, several studies on the influence of partial sleep deprivation or sleep disruption on performance in a non-shiftwork setting. A problem with using the results of most of these studies has been that only night-time sleep was restricted and day-time performance measured (Carskadon and Roth, 1991; Hamilton *et al.*, 1972). This has made it difficult to compare the results to a shiftwork setting where most sleep loss occurs following night shifts, when the subjects sleep is during the day and work is at night (Tepas *et al.*, 1981; Tilley *et al.*, 1981; Walsh *et al.*, 1981; Tepas et a1, 1989)

Experimental studies have shown that performance is significantly impaired if sleep duration or continuity is reduced past a certain point. There is some debate about what the threshold level of sleep is before a reduction in performance is detected. Is it the length, composition or continuity of sleep that is important in influencing performance?

Early reviews (Wilkinson, 1965; Webb 1969) concluded that performance was surprisingly robust to prior sleep reduction and that a reduction of sleep to less than 4 hours was required to significantly influence performance. Wilkinson and colleagues (1966) for example reported reductions in vigilance performance only when sleep was limited to 3 hours or less. This finding was supported by Freidman and colleagues (1977), who found that when sleep was restricted to 4.5-5.5 hours per day there was no significant reduction in performance, although in this study by Freidman and colleagues (1977) performance was not tested often. More recently, Horne and Wilkinson (1985b) reported that after restricting sleep to six hours per night for several weeks, day-time functioning on a performance task sensitive to sleep loss was not significantly reduced compared to controls who were sleeping approximately 8 hours a night. However subjects were only tested once a week and significant practice effects were reported. In these studies sleep restriction was long-term; shiftworkers on the other hand would typically only experience sleep loss sporadically for a week of their roster as on days off they often catch up on lost sleep (Knauth *et al.*, 1980; Tepas *et al.*, 1990).

In contrast to the studies discussed above, Taub and Berger (1976) and Taub (1978) reported that small changes and disruption or irregularities in sleep-wake could produce significant performance impairment. Dinges *et al.* (1997) restricted nocturnal sleep to just below 5 hours for seven consecutive nights and found significant reductions in performance and increased sleepiness. Overall the greatest impairment was observed over the first two days of sleep restriction and it took two recovery days until performance returned to pre-sleep restriction levels.

The following studies suggest that both the timing and duration of sleep influences performance. Taub and Berger (1973) reported that performance was reduced when sleep was restricted to 5 hours and that both the timing and duration of sleep significantly influenced performance. They also observed that by reducing sleep by 3 hours or advancing or delaying sleep by 3 hours from habitual 8-hour sleep, there was a resulting reduction in performance. In comparison, Tilley and Wilkinson (1984) found that when sleep was restricted to either the first or second half of the night, then performance was equally impaired. Furthermore, when sleep was restricted to the second half of the night there was significantly more REM, while the amount of SWS was similar as would be expected due to the circadian rhythm in REM sleep (Endo *et al.*, 1981; Hume *et al.*, 1977). It was concluded that sleep duration may play a more important role in determining performance than the composition of sleep. This is also supported by a recent study by Gillberg and Åkerstedt (1994) who reported that a 4 hour sleep (0300-0700 hours) resulted in longer reaction times compared to an 8 hour sleep condition, although there may be an interaction between sleep duration and timing.

Studies objectively measuring sleepiness following partial sleep loss, have also been carried out. Carskadon and Dement (1981; 1982) conducted multiple sleep latency tests following one night of sleep restricted to 4 hours and after night two when sleep was restricted to 5 hours. Alertness was affected more in the 4-hour sleep condition compared to the 5-hour sleep condition, although alertness was reduced for both conditions. Similar results were reported by Rosenthal *et al.* (1993) when sleep was reduced by less than 2 hours for one night from 7.2-5.6 hours. These studies were all conducted in a non-alerting environment, which is very different from a work environment. It is possible that further reductions in sleep might be required to detect similar increases in sleepiness and reductions in performance in the work place where the environment may be more alerting and motivation increased.

The level of sleep loss required to produce significant reductions in performance may be controversial but the limit of tolerance for prolonged spells of reduced sleep seem to be around 4-5 hours of sleep per day. Testing across multiple days has shown robust practice effects, confounding measurement of cumulative effects and even the use of control groups may not overcome this. In a review of this area by Carskadon and Roth (1991), it was concluded that methodological problems including small sample sizes, narrow types of performance assessed, lack of experimental control over sleep in 24 hours and stimulant use may all be confounding factors in determining the level of sleep restriction required to consistently reduced performance. This suggests that there is a need for more controlled studies. It may also be important to examine sleep reduction for day-time sleep periods and subsequent night-time performance to give a better idea of the effects of sleep reduction on performance of shiftworkers. Another factor that may also influence sleep loss and performance is age; in the next section previous studies of sleep deprivation and restriction comparing older and younger subjects will be discussed.

Age, Continuous Sleep Deprivation and Sleep Reduction

Most of the studies of partial sleep deprivation reported above are conducted on younger subjects. As mentioned previously the sleep of older individuals is often shorter and more fragmented (Miles and Dement, 1980, Webb *et al.*, 1980) and older shiftworkers are reported to have a lower tolerance to shiftwork than their younger counterparts (Tepas *et al.*, 1993; Costa *et al.*, 1989). To date the majority of studies investigating extended or partial sleep deprivation in older subjects have been carried out on individuals 70-80 years of age. Most workers are retired by 65 years of age and these studies, therefore, may be of little relevance to working performance following partial sleep deprivation. Below is a summary of a few of the studies using older subjects, which suggest that there may or may not be a significant difference in performance between older and younger subjects following sleep deprivation.

Brendel and colleagues (1990) investigated total sleep deprivation in both old (80 years) and young (20 years) subjects. While performance was reduced in both groups, it was worse for the younger subjects. They also found that the younger subjects had shorter day-time sleep latencies. They concluded that acute sleep loss was more disruptive in the young compared to the older subjects. It is important to note that they also found that, like Webb and Levy (1972) performance for the older subjects was significantly lower than the younger subjects were to start with. Webb and Levy (1972) also found there were significant differences in performance decrements during sleep deprivation between older and younger subjects.

Bonnet (1989) disrupted sleep (14 x each hour) and reported similar performance decrements on the Wilkinson addition task and vigilance test for subjects in groups with a mean age of 22 and 63 years. They showed that both groups were sensitive to sleep disturbance but that older subjects were less sensitive than the younger subjects were. They suggested that this may be a result of greater sleep inertia in the young compared to the old as testing was completed upon waking.

What these few studies indicate is that while sleep may be equally reduced in younger and older subjects, the influence of the same level of sleep disruption on performance is reduced in the older subjects. It may be that the relative change in performance of the older people due to sleep loss or disruption is less because their performance is lower to start with.

1.8 Summary

The background presented in the preceding introduction indicates that researchers have a reasonably good understanding of the effects of sleep loss on performance, however, performance is influenced by many factors other than sleep. With the increasing number of new and novel shift systems in the multitude of different industries and with an ageing workforce it is important to be able to measure the impact of these schedules on the sleep and the subsequent performance of shiftworkers. To at least in part achieve this the series of experiments in the following chapters were completed.

The first experimental section of this thesis (chapter two) attempts to determine the quantitative similarity between the cognitive psychomotor performance impairment associated with sustained wakefulness and alcohol intoxication, by comparing the performance impairment during 28 hours of sustained wakefulness and at various blood alcohol concentrations up to 0.1%.

The second section (Chapters three, four and five) looks at the influence of age and time-of-day on the correlation between actigraphic and electrophysiological measures of sleep-wake in a simulated shiftwork setting. During the same simulated 12-hour shift rotation Chapters four and five directly compare the difference in sleep and performance between older and younger subjects. By controlling environmental influences and reducing social factors it may be possible to determine, at least in part, the influence of the circadian system on sleep and performance in a simulated 12-hour shiftwork setting.

Finally the third section (Chapters six and seven) will focus on the sleep of shiftworkers in a field-based setting. By looking at the effects of irregular shift schedules and individual factors on the timing and amount of sleep obtained during the twenty four hour day in the rail industry we hope to determine the degree to which sleep-wake behaviour adjusts to an irregular work schedule and how sleep is accumulated during break periods of various durations, for break-onsets at different times of day. This information may enable better scheduling of breaks and provide information to influence policy makers and rostering.

1.9 Preface

This thesis presents three major research studies including:

- a laboratory-based study of sustained wakefulness and alcohol consumption (Experimental Section One - Chapter two)
- a laboratory-based study examining measures of sleep, and sleep and performance in older and younger subjects during a simulated 12-hour shift rotation (Experimental Section Two - Chapters three, four and five)
- a field-based study of sleep in train drivers on irregular schedules (Experimental Section Three - Chapters six and seven).

All three studies were conducted in collaboration with researchers at the Centre for Sleep Research. My role was as project leader on all studies. I was responsible for study design, data collection, entry, analysis and interpretation. As with any large project there were several other researchers that aided with data collection and entry. Specifically Mari-anne Kelly and Ruth Bateson were undergraduate students on exchange for one year. Mari-anne Kelly assisted in onsite data collection and entry for the sustained wakefulness and alcohol consumption studies, the initial laboratory-based 12-hour shift study and field-based railways study. Ruth Bateson assisted in onsite data collection for the second series of 12-hour shift studies and four of the field-based railway studies. Greg Roach assisted in onsite data collection and entry for 10 field-based railway studies and provided statistical advice for the rail project as a research assistant.

All of this research was conducted under the supervision of Prof. Drew Dawson (Chief Investigator on all projects) and Dr. Dave Kennaway.

Ethics approval was given by The Queen Elizabeth Hospital ethics committee for each protocol in this thesis and each subject gave informed written consent.

Experimental Section One

Chapter Two

Quantitative similarity between the cognitive psychomotor performance decrement associated with sustained wakefulness and alcohol intoxication.

2.1 Introduction

Since the industrial revolution shiftwork has become an increasingly common work practice. It has been estimated that 15-20% of the working population in industrialised countries is currently employed on some form of non-standard work schedule (Knauth, 1993; Baker, 1980). While the economic benefits of shiftwork are self-evident (Harrington, 1978), the benefits are accompanied by significant health and social costs (Mitler at al, 1988; Moore-Ede *et al.*, 1985; Spelton *et al.*, 1993). Research studies over the last 20 years have clearly identified shiftwork as an occupational health and safety risk factor (Akerstedt, 1995a).

Reduced opportunity for sleep and reduced sleep quality are generally considered to be the major risk factors associated with shiftwork related accidents (Mitler *et al.*, 1988; Leger, 1994; Akerstedt *et al.*, 1994). Not surprisingly, the combination of these factors leads to increased fatigue, lowered levels of alertness and impaired performance on a variety of cognitive psychomotor performance tasks (Harrington, 1978).

Experimental studies have shown that sustained wakefulness impairs several components of performance including hand-eye co-ordination, decision-making, memory, cognition, visual search performance and speed and accuracy of responding (Linde *et al.*, 1992; Fiorica *et al.*, 1968; Babkoff *et al.*, 1988). In addition to cognitive factors, affective components of behaviour such as motivation, and mood is altered as the duration of sustained wakefulness increases (Babkoff *et al.*, 1988; Bohl, 1993).

There is a general consensus that cognitive psychomotor performance is impaired by the sleep disruption and extended wakefulness associated with shiftwork (Akerstedt *et al.*, 1994). Moreover, this performance impairment is associated with an increased risk of accident (Dinges, 1995).

Surprisingly, however, policy makers in western industrialised countries have generally not legislated to manage and control fatigue in a manner commensurate with the statistical risks associated with it. This attitude is in stark contrast to the response to alcohol-related performance impairment. Policy makers and the community have frequently proscribed work and/or the operation of dangerous equipment under the influence of alcohol. Given that the effects of sustained wakefulness are qualitatively similar to the effects of even moderate alcohol intoxication (Klein *et al.*, 1970), it is paradoxical that fatigue-related performance impairment has not been subject to similar levels of regulatory intervention. This failure to address the occupational, health and safety impact of fatigue may, in part, reflect a failure to provide policy makers with a readily understood index of the relative risk associated with sleep loss and fatigue.

The current study sought to express the performance impairment associated with fatigue with an equivalent that is currently accepted by policy makers and the community, that is to, express the performance impairment as its equivalent level of alcohol intoxication. By expressing the performance impairment associated with fatigue in terms of its equivalent blood alcohol concentration it is hoped to provide an easily-grasped index of comparative impairment.

2.2 Methods

Subjects

Forty subjects (27 male; 13 female) gave informed consent to participate in the study. Subjects ranged from 18 years to 32 years of age (mean 21.1 (± 3.7) years). The subjects selected were recruited using advertisements placed around the University of Adelaide. Volunteers were required to complete a general health questionnaire and a sleep diary prior to the study. Subjects who had a current health problem or a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol or affect sleep patterns were also excluded. Subjects who did not drink alcohol, or who habitually consumed more than 6 standard drinks per day were excluded.

Procedure

All investigations were conducted at the Centre for Sleep Research at the Queen Elizabeth Hospital. Subjects participated in a randomised cross-over design involving two experimental conditions,

1. A sustained wakefulness condition .
2. An alcohol condition.

The two conditions were administered at least one week apart to allow subjects time to recover.

See Figure 1 for a schematic representation of the experimental protocol.

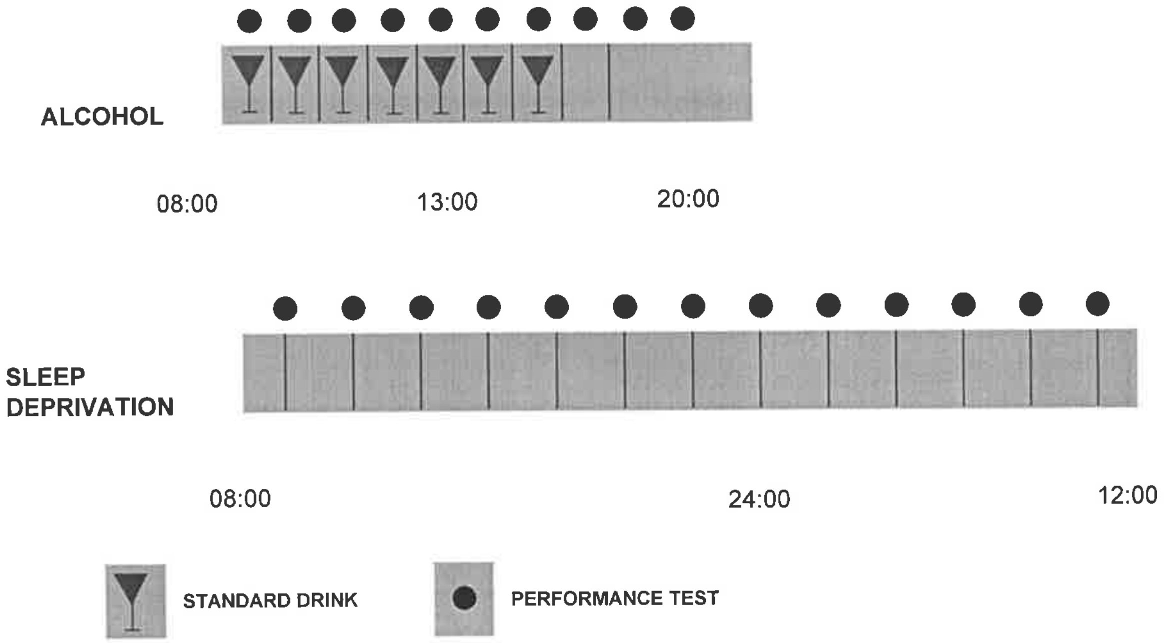

Figure 1. Schematic representation of the protocol for the sustained wakefulness and alcohol experimental conditions. The alcohol condition commenced at 0800 hours. Subjects consumed 10mg of ethanol in orange juice every half hour until 1600 hours or until they reached a BAC of 0.10%. Every 30 minutes, subjects were breathalysed, completed three performance tests and then, if necessary, consumed another alcoholic beverage. The sleep deprivation condition commenced at 0800 hours. Subjects completed three performance tests every 30 minutes until 1200h the following day.

A previous pilot study for this protocol (Dawson *et al.*, 1995) indicated that there was no performance decrement associated with a placebo condition, and that all subjects could correctly identify whether they were intoxicated or not. Since all subjects were regular social drinkers (4-8 drinks/week), and therefore experienced in the effects of alcohol a placebo condition was not included in this protocol.

Training Session

Subjects arrived at the sleep laboratory at 2030 hours on the night prior to the commencement of each study period. They were required to complete 40 Occupational

Safety Performance Assessment Tests (OSPAT) to familiarise themselves with the assessment procedure and to minimise improvement in performance resulting from learning.

Sustained Wakefulness Condition

Subjects arrived at the sleep laboratory at 2030 hours on the night prior to the commencement of the study period and completed a training session before going to sleep at approximately 2300 hours. Subjects were woken at 0700 hours the following morning. After breakfast at approximately 0745 hours, 9 practice OSPAT tests were completed. Subjects then completed three performance tests at half hourly intervals from 0800 hours until 1200 hours the following day. In between tests, subjects were allowed to read, watch television and play games. Careful monitoring by research staff ensured wakefulness over the entire 28-hour period.

Alcohol Condition

Subjects arrived at the sleep laboratory at 2030 hours on the night prior to the commencement of the study period and were required to complete a training session before going to sleep at approximately 2300 hours. Subjects were woken at 0700 hours the following morning, after breakfast at approximately 0745 hours, 9 performance tests were completed. From 0800 hours subjects underwent a breath test, completed three OSPAT tests and consumed an alcoholic drink at half hourly intervals. If a BAC of 0.1% was reached no further alcohol was given. Subjects were not informed of the BAC at anytime during the test period. All drink consumption and performance testing ceased at 1600h, but subjects were required to stay in the sleep laboratory under supervision until their BAC returned to 0%.

Subjects ate standard hospital meals during the study, although food and drinks containing caffeine were prohibited. Subjects were required to sit quietly and watch television or play board games during their time in the laboratory. Subjects were not permitted to exercise, shower or bath.

Equipment

Cognitive psychomotor performance

Cognitive psychomotor performance was measured using the Occupational Safety Performance Assessment Test (OSPAT). OSPAT is a unpredictable tracking task that subjects perform on a computer workstation. In simple terms, the task required subjects to keep a randomly moving cursor in the centre of three concentric circles, using a standard trackball. After the cursor is 'centred' the cursor moves to a random position away from the centre and the subject is required to 're-centre' the cursor. Subjects were seated in front of the workstation in an isolated room, free of distraction and were instructed to manipulate the track-ball using their dominant hand. Subjects completed three one-minute tests in each testing session and received no feedback between tests in order to avoid the knowledge of results affecting performance levels.

A global performance measure for each test is determined by summing the 'error' distance between the cursor and target and the rate at which the subject adapted to the random changes. This measure indicates how "well" the subject performed the task.

Blood alcohol

During the alcohol condition subjects were given alcohol loaded drinks consisting of 95% ethanol and orange juice at a rate designed to increase their BAC to 0.10% over a 4-6h period. Prior to all breath tests subjects were required to rinse their mouths with water. A standard calibrated breathalyser was used to estimate blood alcohol concentration (BAC) (Lion Alcolmeter S-D2, Wales). The breathalyser was accurate to 0.005% BAC.

2.3 Analysis of Results

Cognitive psychomotor performance data was analysed using relative performance. That is, each individual's performance was expressed relative to their personal baseline. Relative performance for the training session and two experimental conditions was expressed relative to baseline where baseline performance was assigned a relative value of one. The baseline measure was calculated by averaging the scores of the nine practice trials carried out prior to the first 0800 hours performance test on the first of the two counterbalanced experimental conditions for each individual. The rationale for choosing these trials was to eliminate the confounding effects of task learning.

Figure 2 indicates that subjects rapidly mastered the performance test during the practice session. There was little variation in mean relative performance after completing 5 tests and by 25 tests subjects had reached a clear performance plateau.

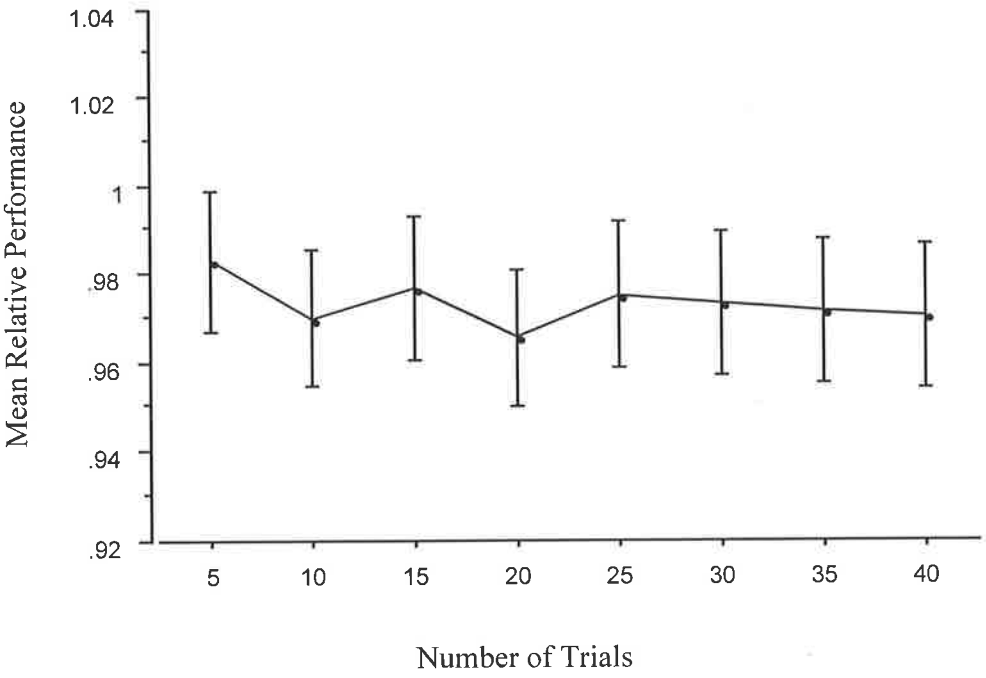

Figure 2. Mean relative performance for training session trials in the night prior to the first experimental condition. Error bars indicate ± s.e.m.

Sustained Wakefulness Condition

Performance in the sustained wakefulness condition was analysed by averaging performance data into two-hourly bins across the 28 hours of the study. Since there is a strong non-linear (circadian) component to the performance data and shiftworkers do not typically spend less than 10 or more than 26 hours awake (Australian Bureau of Statistics, 1993), the linear performance decrement per hour of wakefulness, was calculated using a linear regression between the tenth and twenty-sixth hour of wakefulness. This was methodologically appropriate since analysis of the performance data across this period shows a significant linear component (p<.05) and a non-significant non-linear component. Figure 3. illustrates this relationship plotting mean relative performance against hours of wakefulness between the tenth and twenty-sixth hours.

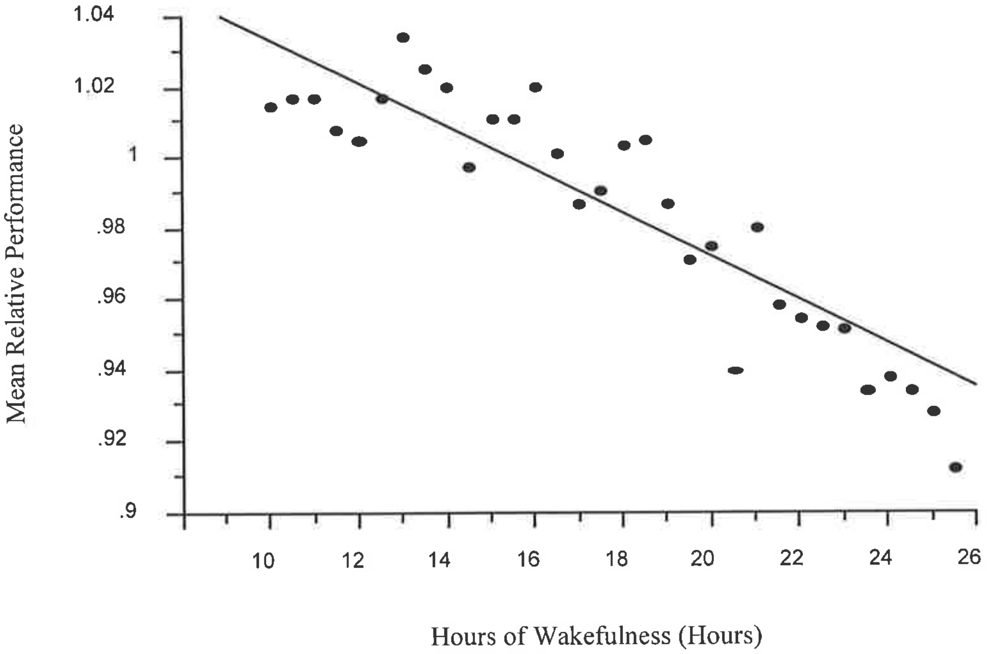

Figure 3. Scatterplot and linear regression of mean relative performance levels against prior wakefulness between the 10th and 26th hour of sustained wakefulness.

Regression analysis revealed a significant linear correlation ($F(1,24) = 132.9$, $p < 0.05$, $R^2 = 0.92$) between mean relative performance and hours of wakefulness. Between the tenth and twenty-sixth hours of wakefulness, performance relative to baseline decreased by 0.74%/h.

Alcohol Condition

To determine the relative effect of alcohol on performance, mean relative performance scores for all subjects were collapsed into 0.005% BAC intervals to determine the average performance decrement per unit increase of BAC. The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.005% interval. Figure 4, shows the regression line between estimated BAC and mean relative performance in the alcohol condition.

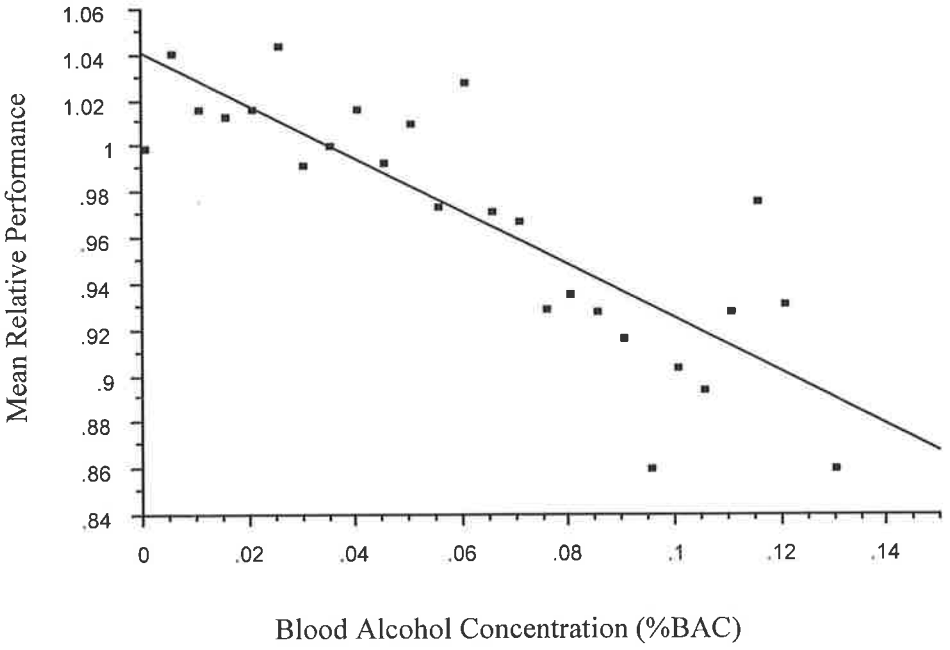

Figure 4. Scatter plot and linear regression of mean relative performance levels against blood alcohol concentrations between 0.00-0.13%.

The regression analysis indicated a significant linear correlation (F(1,24) 54.4, $p<0.05$, $R^2=0.69$) between subjects mean BAC and mean relative performance. It was found that for each 0.01% increase in BAC, performance decreased by 1.16%. Thus, at a mean BAC of 0.10% mean performance decreased, on average, by 11.6%.

Sustained Wakefulness and Alcohol Condition

The results discussed above illustrate the effects of sustained wakefulness and alcohol intoxication on cognitive psychomotor performance. However, the aim of the present study was to express the effects of fatigue as a blood alcohol equivalent. Figure 5, illustrates the comparative effects of sustained wakefulness and alcohol consumption on performance by plotting mean relative performance and BAC against hours of wakefulness.

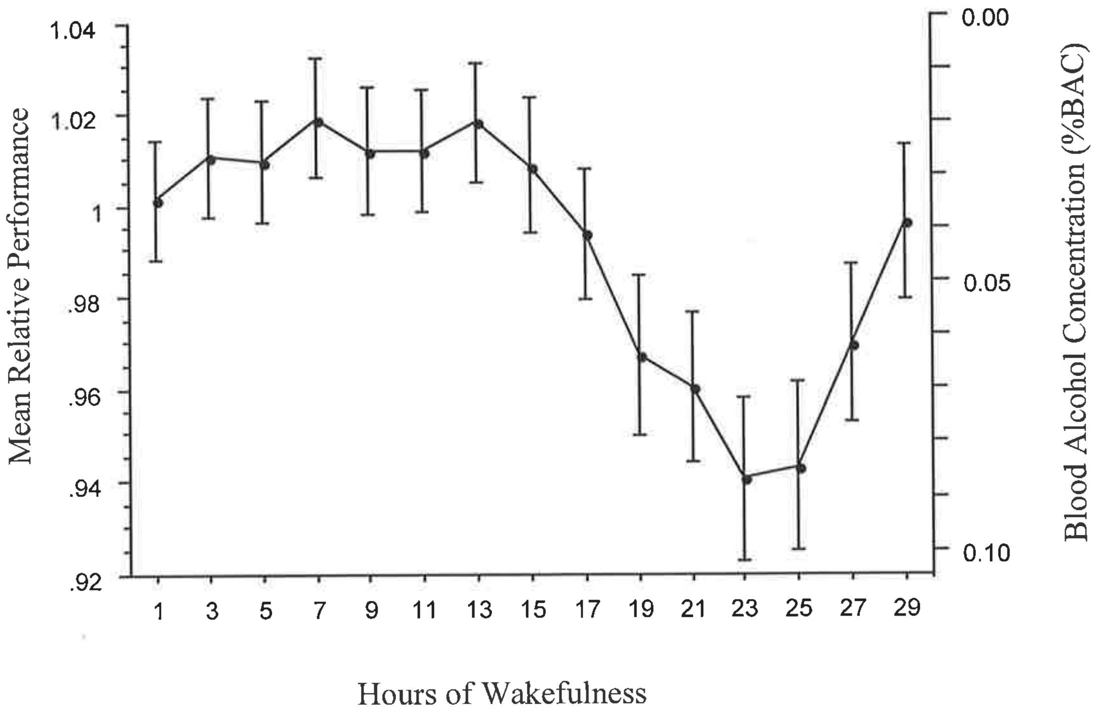

Figure 5. Performance in the sustained wakefulness condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate ± one s.e.m.

By equating the two rates at which performance declines, (i.e. % decline / hour of wakefulness and % decline / ΔBAC) it was calculated that the performance decrement for each hour of wakefulness was equivalent to the performance decrement observed with a 0.04% rise in BAC. Therefore, after 24 hours of sustained wakefulness cognitive psychomotor performance decreased to a level equivalent to the performance observed at a BAC of 0.096%.

2.4 Discussion

Cognitive psychomotor performance levels decreased significantly in both the alcohol (0800-1600 hours) and sustained wakefulness (1700h-0900 hours) conditions. Comparison of the two effects indicated that moderate levels of sustained wakefulness (between 1700-0900 hours) produce performance decrements comparable to those observed at moderate levels of alcohol intoxication (between 0800-1600 hours) in social drinkers.

In the alcohol condition increasing blood alcohol concentrations were associated with a significant linear decline in cognitive psychomotor performance. Mean relative performance in the alcohol condition was impaired by approximately 5.8% at a BAC of 0.05% and by 11.6% at a BAC of 0.10. Overall, mean relative performance declined by approximately 1.16% per 0.01% BAC. These results are consistent with previous findings that suggest that cognitive psychomotor performance declines linearly with increasing intoxication between 0.0-0.075% BAC (Billings *et al.*, 1991).

It is important to note that there was no decrease in mean relative performance up until a BAC of 0.03%. This is similar to the findings of Wilkinson and Colquhoun (1968) who also reported an increase in performance on a choice serial reaction test up until a BAC of 0.032%. This result is thought to reflect the fact that alcohol acts as a stimulant at low blood alcohol concentrations.

In contrast, cognitive psychomotor performance in the sustained wakefulness condition showed a more complex relationship. Mean relative performance showed three distinct phases. In the first phase (0-10 hours) performance remained relatively stable at a plateau. In the second phase (10-26 hours) performance declined linearly. During the third interval (26-28 hours) mean relative performance increased again presumably reflecting the well reported circadian variation in cognitive psychomotor performance (Folkard *et al.*, 1993).

Since few shiftworkers remain awake for less than 10 or more than 26 hours between shifts (Australian Bureau of Statistics, 1993), the comparative analysis focused on the second phase. Between the 10th and 26th hours mean relative performance, showed a strong linear decline of approximately 0.74 % per hour. The performance decline observed between hours 10 and 26 (which fell between 1700-0900 hours) is consistent with previous studies, documenting cognitive psychomotor performance decreases for periods of sustained wakefulness between 12 and 86 hours (Linde *et al.*, 1992; Storer *et al.*, 1989; Fiorica *et al.*, 1968).

While the results in each of the individual experimental conditions have, in and of themselves been previously established (Linde *et al.*, 1992; Storer *et al.*, 1989; Wang *et al.*, 1992; Gustafon, 1986; Roache *et al.*, 1992) equating the effects is relatively novel.

The results of this comparison indicate that the effects of 10-26 hours of sustained wakefulness from 1700-0900 hours, and moderate alcohol consumption between 0800-1600 hours have quantitatively similar effects on cognitive psychomotor performance. Although there are previous, anecdotal reports, indicating qualitative similarities between fatigue and alcohol intoxication (Klein *et al.*, 1970), this study establishes the quantitative similarities of the two forms of impairment. In this study, equating the performance impairment between the 10th and 26th hour indicated a mean BAC equivalent of approximately 0.05% after 18 hours (at 0100 hours) and 0.096% after 24 hours (at 0700 hours) of wakefulness.

If the results of this study were generalised to an applied setting they suggest that between 0300 hours and 0800 hours on the first night shift a shiftworker would show a cognitive psychomotor performance decrement similar to or greater than the legally proscribed BAC for many industrialised countries.

The data supports the idea that moderate levels of sustained wakefulness in the early hours of the morning may carry a risk comparable with moderate alcohol intoxication. Since approximately 50% of shiftworkers on 8 hour shift patterns typically spend at least 24 hours awake on the first night shift in a roster there could be serious implications for worker safety (Knauth *et al.*, 1981). Furthermore, the highest level of impairment observed in this study (~0.096% BAC) would occur at the end of a typical night shift (i.e. 0600-0900 hours) and would frequently coincide with the trip home for many shiftworkers.

While the results of this study clearly illustrate the comparative risks associated with sustained wakefulness for the first night shift, these results may underestimate the effect of night work in many real world settings. Previous research suggests that the performance impairment associated with shiftwork may be even greater on subsequent night shifts because of the reduced recuperative value of poor daytime sleep (Akerstedt, 1995b). Studies have reported that the performance decrements, reduced alertness and fatigue reported by night shiftworkers is greater on the second and third night shift (Tilley *et al.*, 1981). If this is the case, then it may be reasonable to assume that the alcohol impairment equivalent on these nights may be even greater than reported here for the first night.

However, it is not a simple process of calculating the performance decrement for hours of wakefulness, since shiftworkers may be sleeping at different times of the day and night. In addition they may have accumulated sleep loss from night one to three of their work schedule. Therefore, it may be useful to use longer experimental protocols to model actual shift schedules and establish the BAC equivalence for the performance decrement associated with the fatigue that can accumulate over a sequence of night shifts.

Taken together, the results from this study support the idea that the performance impairment and, by inference, the risk associated with sustained wakefulness across the night are not insubstantial and are quantitatively similar to those observed for moderate alcohol intoxication in social drinkers.

Experimental Section Two

Chapter Three

Correlation between actigraphic and electrophysiological measures of sleep in a simulated shiftwork environment for younger and older subjects.

3.1 Introduction

Shiftwork has become an increasingly common work practice in most industrialised countries, with 15-20% of the workforce employed in some form of shiftwork (U.S. Congress, Office of Technology Assessment, 1991; Wedderburn, 1993; Australian Bureau of Statistics, 1993). Within this group, sleep disruption, specifically reduced sleep quality and duration, is a commonly reported problem (Rutenfranz *et al.*, 1985; Tilley *et al.*, 1981; Akerstedt *et al.*, 1990). Such reductions in sleep may lead to increased sleepiness and fatigue, and reduced alertness on the job (Akerstedt *et al.*, 1982). Shiftwork related fatigue is believed to increase the risk of accidents and has played a role in several major industrial accidents, for example the Exxon Valdez and Three Mile Island disasters. For this reason, shiftwork has been identified as a significant occupational health and safety risk factor (Mitler *et al.*, 1988; Leger, 1994; Ehret, 1981; Mitler and Miller, 1996, Akerstedt *et al.*, 1994).

Quantitative studies to determine the duration and quality of sleep in shiftworkers typically restrict subjects to laboratory settings or require invasive monitoring using electrophysiological techniques (Torsvall and Akerstedt, 1987: Foret and Latin, 1972; Tilley *et al.*, 1981; Foret and Benoit, 1974). In recent years, actigraphy has been suggested as a viable alternative to electrophysiological measures of sleep (Tryon, 1991; Sadeh *et al.*, 1995). The activity monitor is small, approximately the size of a wrist watch and can be worn all day and night with little impedance to the subjects lifestyle. In contrast, electrophysiological techniques require the experimenter to constantly interact with the subject, making it difficult to record 24 hours a day for extended periods of time. Due to its small size and ease of use the activity monitor may

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be a simpler, more cost effective and less invasive as a method of recording sleep/wake behaviour in a field-based setting.

Previous research has reported a high correlation between electrophysiological and actigraphic measures of sleep in patient and normal populations (Kripke *et al.*, 1978; Mullaney *et al.*, 1980; Sadeh *et al.*, 1989, Cole *et al.*, 1992). Epoch for epoch agreement between electrophysiological and actigraphic sleep-wake scoring has been between 78-96% (Sadeh *et al.*, 1989; Mullaney *et al.*, 1980). While for measures of sleep efficiency and sleep duration correlations between 0.63-0.98 (Sadeh *et al.*, 1989; Kripke *et al.*, 1978) and 0.82-0.97 (Mullaney *et al.*, 1980; Kripke *et al.*, 1978) respectively have been reported.

Although studies have examined the correlation between nocturnal electrophysiological and activity measurement in both normal and patient populations (Kripke *et al.*, 1978; Mullaney *et al.*, 1980; Sadeh *et al.*, 1989, Cole *et al.*, 1992), validation studies of actigraphically measured sleep in shiftworking populations have not been reported. Since shiftworkers often sleep during the day, as well as at night, it is important to examine day- and night-time correlations of actigraphy with electrophysiological techniques. In addition, there is some evidence to suggest that the correlation between actigraphy and EEG is lower in older subjects (Mullaney *et al.*, 1980). This may be the result of age related changes in activity levels (Lieberman *et al.*, 1989).

The aim of this study was to investigate the correlation between sleep recorded using electrophysiological and actigraphic techniques in young and older individuals for both day-and night-time sleep periods during a simulated 12-hour shift rotation.

3.2 Methods

Subjects

Twenty-five male and seven female subjects participated in this study. Subjects were allocated to groups according to age. The first group was aged between 18-30 with a mean (±s.d.) age of 21.2 ± 2.7 years, and the second group was aged between 35-56 with a mean (±s.d.) age of 43.9 ± 6.8 years. All subjects were screened by interview, general health questionnaire and a two week sleep diary. Subjects who smoked, were using medication, or had a history of sleep disorders were excluded.

Procedure

Figure 1 is a schematic representation of the experimental protocol.

Subjects entered the laboratory at 1700 hours on day one of the study for an adaptation night. During the night saliva was collected each hour between 1800-0300 hours. On average subjects were woken for approximately 2-5 minutes each hour 2300 hours to 0300 hours for saliva collection (the results of this analysis will be presented in a subsequent paper) with a resulting 10-25 minutes of wakefulness on average across the night. Considering the short nature of the arousal and the fact that the data from the adaptation night is not analysed I feel that there will be little if any influence of the saliva collection on subsequent performance or sleep. Following the adaptation night subjects underwent a simulated 12-hour shift rotation. During this time they completed two 12-hour day shifts between 0700-1900 hours, followed by two 12-hour night shifts between 1900-0700 hours. Subjects self selected sleep times, but were awoken approximately one hour before their shift commenced if they did not wake themselves. Each subject had their own room, in which environmental factors such as light, noise and temperature were controlled. Sleep / activity was recorded by both standard polysomnography and a wrist activity monitor.

Time for both the Polysomnography (PSG) sleep recordings and activity monitors were synchronised, so that individual 30 second epochs could be compared.

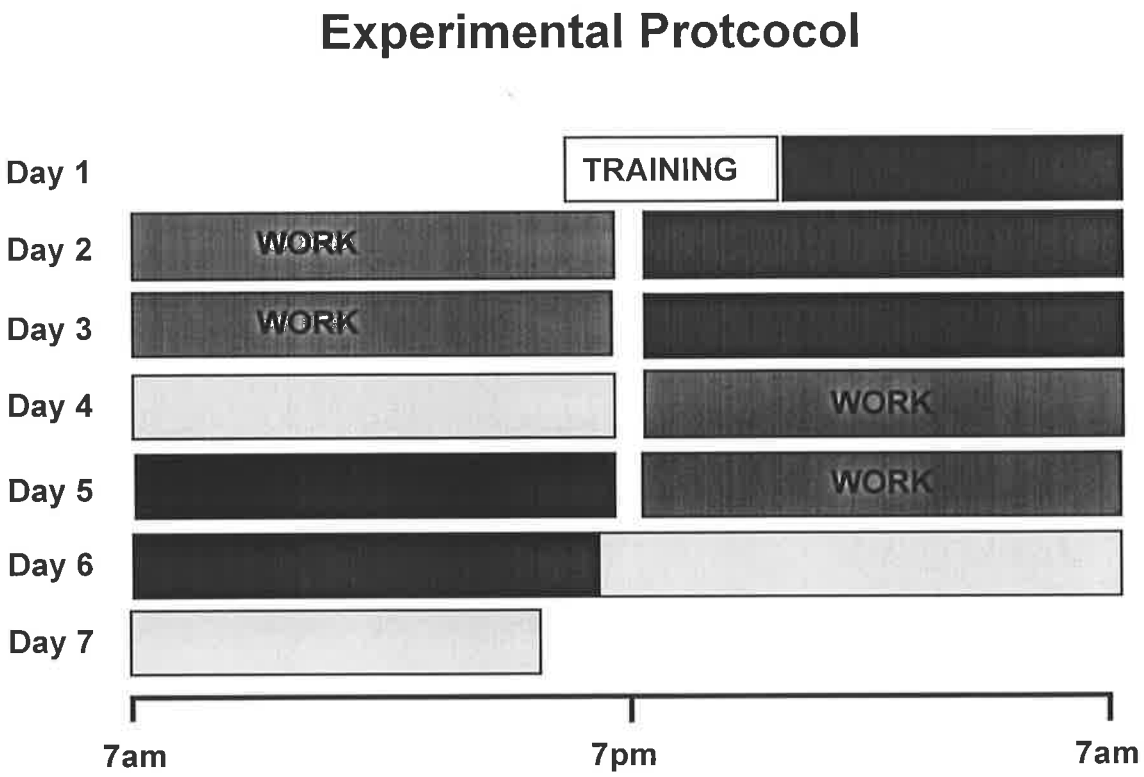


Figure 1. Schematic representation of the experimental protocol. Subjects underwent an adaptation night (day one). Adaptation was followed by two 12-hour day shifts (day 2 & 3), and then two 12-hour night shifts (day 4 & 5). During the periods that subjects were able to sleep (black areas) they were wired for standard polysomnography, and wore an activity monitor for the entire 7 days of the study.

Sleep / Wake

Actigraphy

Subjects wore wrist activity monitors Z80-32k V1 (Gaehwiler Electronic) on their non-dominant hand throughout the protocol.

The wrist activity monitors are piezo-electric accelerometers with a sensitivity of 0.1 g. The sampling time of the monitor is 125 ms (8 Hz) and the analog sensor is filtered by a band-pass filter of 0.25-3.0 Hz. The activity count recorded for each epoch (in this case 30 seconds) is the proportion of the epoch spent moving with a force greater than 0.1g expressed using eight-bit resolution (i.e. 0-255 steps). Therefore, for each epoch stored activity values vary between 0 and 253. The maximum value of 253 indicates that supra-threshold activity is present in all time windows (125 ms period) throughout the measuring interval (i.e. 30 secs).

Polysomnography

Sleep quality and duration were also determined using standard polysomnography (PSG) collected in 30 second epochs. A standard electrode montage was used with EEG (C3-A2, 02-A1), EOG and EMG. Electrophysiological data were sampled at 500 Hz and stored at 250 Hz using an Oxford sleep analysing computer (SAC-847, Oxford Medical Inc., UK). Electrophysiological data were obtained within a 70 Hz bandwidth, with a low-filter-cut-off of 0.33 Hz. PSG recordings were visually scored in thirty-second epochs, according to standard criteria (Rechtschaffen and Kales, 1968), and then rated as sleep or wake for time-matching analysis of PSG and actigraphy.

Sleep/Wake Diary

Subjects completed a sleep diary daily upon final waking (to ensure more accurate recall of sleep) recording all sleep periods including awakenings. Subjects were also asked to rate the quality of their sleep, on a scale from 1-5, with one being a good sleep and five being a poor sleep. In addition, subjects were asked to rate how sleepy or awake they felt before going to sleep and when they woke up using the 7 point Stanford Sleepiness Scale (SSS).

3.3 Analysis of Results

Epoch for epoch agreement

Each individual 30-second epoch of actigraphy and polysomnography was directly compared. The frequency distribution of the epoch for epoch agreement was calculated and given a number from 1-4 to define the nature of the agreement or disagreement between epochs, for example:

1 = actigraphy count of 0 and EEG awake (stage 0)
2 = actigraphy counts of ≥ 1 and EEG sleep (stage 1-4, REM)
3 = EEG sleep (stage 1-4, REM) and actigraphy count of 0
4 = EEG awake (stage 0) and an actigraphy score of ≥ 1

The number of true positives (TP), false positives (FP) and false negatives (FN) was calculated as follows (adapted from Drinnan *et al.*, 1996):

	EEG	
Actigraphy	awake	asleep
active	**4** (True Positive)	**2** (False Positive)
inactive	**1** (False Negative)	**3** (True Positive)

Sensitivity and Positive Predictive Accuracy

Sensitivity (sens) and positive predictive accuracy (PPA) for each subject was calculated as follows (Drinnan *et al.*, 1996):

$$\text{Sensitivity} = \frac{TP}{TP+FN}$$

$$\text{Positive Predictive Accuracy} = \frac{TP}{TP + FP}$$

Sleep Onset, Sleep Offset and Sleep Duration

Sleep onset and offset for EEG was scored using standard criteria. Actigraphic sleep onset was scored as the first epoch with a 0 count of movement following ten consecutive epochs with a 0 count of movement (5 mins). Sleep offset was scored as the first epoch of movement 1 or greater followed by ten consecutive epochs of movement. The mean difference between EEG and actigraphic sleep onset as well as sleep offset was calculated. In addition, from the actigraphic onset and offset, sleep duration was calculated and a Pearson r correlation between sleep duration for EEG (Sleep Period Time) and actigraphy was determined.

Sleep Efficiency

Sleep efficiency was calculated for both measures of sleep / wake activity. EEG sleep efficiency (EEG.SE) was calculated as the Total Sleep Time / Total Time Recorded x 100. Actigraphically recorded Movement Index (MI) was calculated as the percentage of the sleep period in which the subject is active (activity count greater than 0) and has previously been shown to be highly correlated with electrophysiological sleep efficiency (Sadeh *et al.*, 1989; Kripke *et al.*, 1978). For ease of comparison movement index will be termed as actigraphic sleep efficiency (ACT.SE). In addition, it was altered to the proportion of the sleep period spent without movement by subtracting the MI from 100 and expressing it as a percentage.

As sleep efficiencies (SE) were not normally distributed, a Spearman ranked correlation coefficient was used to determine the correlation between EEG.SE and ACT.SE (see Figure 3).

3.4 Results

Epoch for epoch agreement

The frequency distributions of the epoch for epoch agreement, between EEG and actigraphy are shown in Table 1.

There was no significant difference between the epoch for epoch agreement for day-time and night-time sleep periods in the young group. However, in the older group the epoch for epoch agreement was significantly lower for the day-time sleep periods when compared to the night-time sleep periods ($p<0.05$). In addition, for day-time sleep periods in the older group, there was a significant increase ($p<0.05$) in the proportion of epochs scored as inactive / awake (FN), or lying still while awake. During the night-time sleep periods FN were on average 5.94 – 5.84 for the older subjects. For the older subjects during the day-time sleep periods FN were 9.94 – 15.29 on average.

In addition, planned comparisons revealed that there was no significant difference between younger and older subjects in the epoch for epoch agreement for night-time sleep periods. However, TP (3 & 4) for the second day-time sleep period in the older subjects were significantly lower than for the younger subjects $p<0.05$, while FN (1) for day-time sleep period two in the older subjects was significantly higher than for the same sleep period in the younger subjects ($p<0.05$).

Table 1. Mean percentage frequency distributions of the epoch for epoch agreement between EEG and actigraphy for (a) young and (b) older subjects on night (2 & 3) and day-time (1 & 2) sleep periods.

(a)Young Subjects

Night 2 (EEG)

Actigraphy	awake	asleep
active	5.12	5.73
inactive	5.21	83.92

Night 3 (EEG)

Actigraphy	awake	asleep
active	4.84	5.10
inactive	5.71	84.33

Day 1 (EEG)

Actigraphy	awake	asleep
active	4.09	6.13
inactive	6.71	83.05

Day 2 (EEG)

Actigraphy	awake	asleep
active	4.87	8.55
inactive	6.08	80.48

(b) Older Subjects

Night 2 (EEG)

Actigraphy	awake	asleep
active	4.75	6.13
inactive	5.94	84.02

Night 3 (EEG)

Actigraphy	awake	asleep
active	4.06	6.87
inactive	5.84	82.87

Day 1 (EEG)

Actigraphy	awake	asleep
active	8.99	6.31
inactive	9.94	74.75

Day 2 (EEG)

Actigraphy	awake	asleep
active	10.16	5.79
inactive	15.29	68.90

Sensitivity and Positive Predictive Accuracy

Sensitivity and positive predictive accuracy were calculated and are presented in Figure 2. Sensitivity and Positive Predictive Accuracy were between 89-93% and 92-93% respectively for all sleep periods.

Repeated measures ANOVA indicated no significant difference between day and night sleep periods for positive predictive accuracy or sensitivity. However there was a significant interaction effect for age and sensitivity (F (3,)= 2.702, $p < 0.05$). Post-hoc paired t-tests revealed a significant difference between sensitivity in the young and older subjects for the second day-time sleep period ($p > 0.015$) see Figure 2.

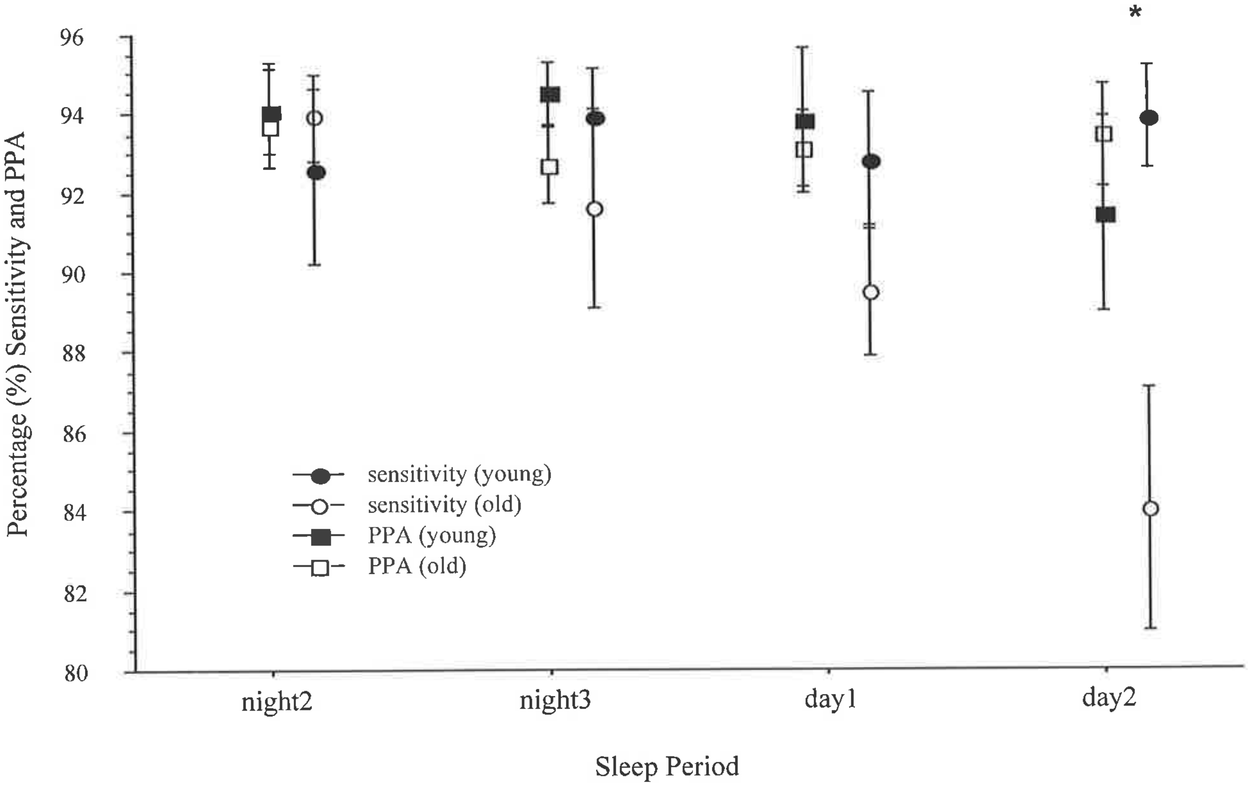


Figure 2. Graph of Sensitivity and Positive Predictive accuracy (mean ± s.e.m) for young (closed circles & squares) and older (open circles & squares) subjects for day and night-time sleep periods for older and younger subjects. * Indicates significance level $p < 0.05$.

Sleep Duration, Sleep Onset and Offset

Pearson correlation coefficient showed that there was a high correlation between sleep duration recorded by EEG and the sleep duration recorded by actigraphy. Correlations for the young subjects were between 0.77- 0.98 and for the older subjects correlations were between 0.69-0.96 (see Table 2).

Table 2. Pearson correlation for electrophysiological and actigraphic sleep duration's, for night and day-time sleep periods in both young and older subjects.

Sleep	Night-Day	Pearson-r Young	Pearson-r Old
2	Night	0.91	0.78
3	Night	0.77	0.96
4	Day	0.96	0.91
5	Day	0.98	0.69

In addition, the mean difference between EEG and actigraphic sleep onset and EEG and actigraphic sleep offset was calculated and analysis is presented in Table 3.

Table 3. Mean (± s.e.m.) difference in electrophysiologically and actigraphically recorded sleep onset and sleep offset in young and older subjects in minutes.

Sleep	Night-Day	Young.onset	Old.onset	Young.offset	Old.offset
2	Night	7.2 (3.2)	11.4 (3.6)	9.2 (3.7)	6.8 (1.9)
3	Night	20.9 (11.4)	9.2 (2.3)	4.6 (1.5)	3.7 (1.3)
4	Day	6.8 (3.4)	8.4 (3.0)	17.7 (8.3)	19.9 (8.0)
5	Day	9.8 (5.7)	6.8 (1.6)	32.9 (10.3)	16.0 (4.3)

Sleep Efficiency

Details of sleep period, mean lights out, lights on, mean (± s.e.m.) sleep efficiency for EEG and actigraphy and Spearman ranked correlations for both groups are presented in Table 4 a) and b).

On average, during the day-time sleep periods, EEG sleep efficiencies in the older group were significantly lower ($p<0.05$) than the night-time sleep periods and lower than sleep efficiencies in the younger group (Table 4).

In the younger group, Spearman ranked correlation coefficient revealed that there was a higher correlation between night-time sleep efficiencies (0.72-0.76) determined by EEG and actigraphy, than for day-time sleep periods (0.15-0.57). In contrast, for the older group, Spearman ranked correlation coefficient revealed low correlations between EEG and actigraphic sleep efficiencies for all sleep periods (-0.18-0.58).

Scattergrams of the sleep efficiencies for EEG and actigraphy for both younger and older subjects are shown in Figure 3, and reveal that there is a narrow range in sleep efficiencies for EEG and actigraphy particularly for the older age group on night 3.

Table 4. Mean (± s.e.m.) Sleep period, night or day-time, lights out, lights on, EEG sleep efficiencies (EEG.SE), ACT sleep efficiencies (ACT.SE), with correlations between EEG.SE and ACT.SE in (a) young and (b) older subjects.

(a)

Sleep	Night-Day	Lights out	Lights on	EEG.SE	ACT.SE	Spearman
2	Night	23:21	6:06	86.12 (2.3)	89.8(1.7)	0.72
3	Night	24:02	06:20	85.52(1.9)	89.8(1.8)	0.76
4	Day	08:07	16:43	85.11(2.3)	90(71.8)	0.57
5	Day	07:44	15:20	85.34(1.7)	89.2(1.1)	0.15

(b)

Sleep	Night-Day	Lights out	Lights on	EEG.SE	ACT. SE	Spearman
2	Night	23:40	6:03	83.94(2.2)	91.59(0.8)	0.58
3	Night	23:30	6:12	85.06(1.2)	92.24(0.7)	-0.18
4	Day	8:02	15:51	77.29(3.8)	86.52(1.5)	0.52
5	Day	7:45	14:17	69.87(4.7)	86.74(1.7)	0.35

Correlation between EEG and actigraphic measures of sleep

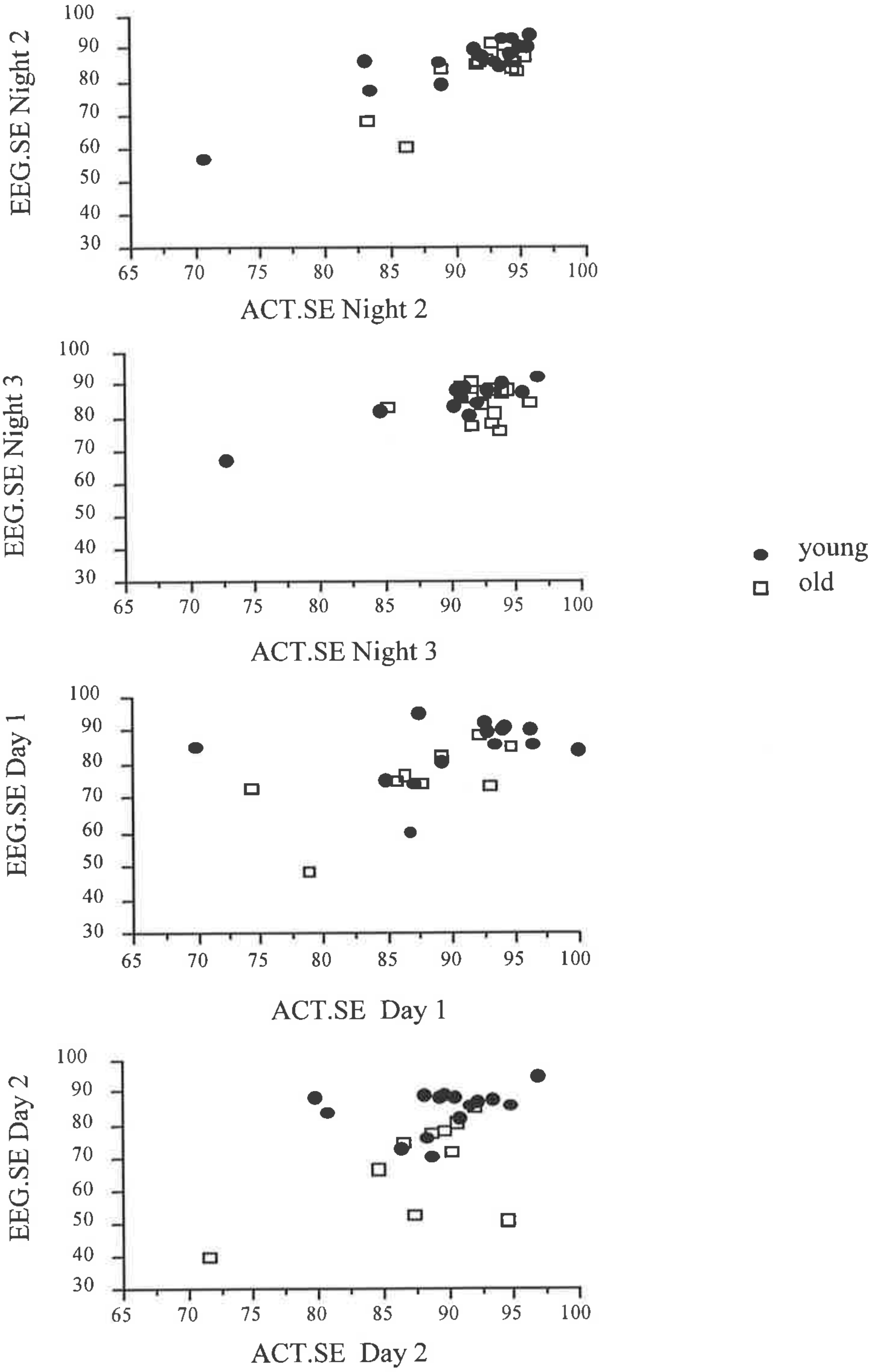


Figure 3. Scattergrams of the individual electrophysiologically and actigraphically recorded sleep efficiencies in young (closed circles) and older (open squares) subjects for day and night-time sleep periods.

3.5 Discussion

Comparison of electrophysiological and actigraph measures of sleep/wake behaviour indicate that while actigraphy is a reliable measure of night and day-time sleep periods, some caution should be used for more specific measures such as sleep efficiency. In addition, age and time of sleep period appear to be significant factors in determining the reliability of actigraphy as an accurate measure of sleep/wake behaviour.

In the young subjects, on average, electrophysiological sleep/wake activity was correctly recorded by actigraphy 85-89 % of the time. The 10-15 % disagreement between EEG and actigraphy was as often an error of actigraphy scoring inactivity when subjects were awake (FN) as scoring activity when asleep (FP).

In contrast, for the older subjects, electrophysiologically recorded sleep/wake activity was on average correctly identified by actigraphy 79-88 % of the time. In addition, in the older group, during the day-time sleep periods, actigraphy was twice or three times as likely to score sleep when EEG recorded awake (false negative (1)). This may be attributed to older subjects spending more time during the daytime sleep periods awake, than younger subjects (see chapter four). This suggests that in the older subjects, during the day, actigraphy is less able to detect quiet wakefulness (subjects are lying still but awake). These findings are comparable to those of Mullaney and colleagues (1980) who reported in a group of normal and patient subjects, that the minute-by-minute PSG and actigraphic agreement was significantly lower for those aged 50 and above compared to younger subjects.

Previous studies have reported that the epoch for epoch agreement between EEG and actigraphy ranges from 96.3 in normal subjects to 78.2 in insomniacs (Mullaney *et al.*, 1980; Sadeh *et al.*, 1989). In the current study, the epoch for epoch agreement for the older subjects sleeping during the daytime is comparable to that observed for insomniacs. In contrast, for the younger subjects during the day-time sleep periods, the epoch for epoch agreement is comparable to that reported at the lower end of normal subjects groups. Differences in the epoch for epoch agreement between the current study and others, may be due to other studies using minute epochs rather than 30 second epochs. Increasing the length of the sampling period may increase the match between EEG and actigraphy. Another factor that may influence the epoch for epoch agreement is that short sleepers (<390 minutes) have been found to have a lower minute-minute agreement than longer sleepers (>390 minutes) (Mullaney *et al.*, 1980). In the current study, all subjects typically slept (Total Sleep Time) less than 390 minutes.

In an attempt to determine the ability to detect false negatives and false positives, Positive Predictive Accuracy (PPA) and Sensitivity (Sens) respectively were calculated for all sleep periods (adapted from Drinnan *et al.* 1996) and separated for age (see Figure 2). The results of this analysis revealed that PPA was between 91.4%-94.5% in the young group and between 92.7%-93.7% in the older group. While Sensitivities in the younger group were between 92.5%-93.9% and between 84.9%-94% in the older group. In contrast, patients with suspected respiratory disorders were reported as having an average PPA of approximately 60% and a Sensitivity of approximately 70% (Drinnan *et al.*, 1996). However, use of a patient population rather than normal subjects would account for this difference.

Furthermore, for the older subjects, sensitivity for day-time sleep periods was on average lower compared to the night-time sleep periods. In addition, for the second day-time sleep period, sensitivity in the older subjects was significantly lower, when compared to the younger subjects. This reduction in sensitivity during the day-time sleep periods is a result of the lower match between EEG and actigraphy. This is consistent with the finding that actigraphy was less proficient at determining active / asleep (FP) in the older subjects during the day.

Significant reductions in sleep duration and sleep quality are commonly reported in shiftworkers (Rutenfranz *et al.*, 1985; Tilley *et al.*, 1981; Akerstedt *et al.*, 1990; Foret and Benoit, 1974; Frese *et al.*, 1984). Therefore, the correlation between actigraphic and EEG recorded sleep duration and sleep efficiency measures were calculated. The results of this analysis revealed that there was a high correlation between actigraphically and electrophysiologically recorded sleep duration both during the day and night in young (0.77-0.98) and older (0.69-0.96) subjects (see Table 2). These results are similar to those reported by Kripke *et al.*, 1978; Mullaney *et al.*, 1980; Sadeh *et al.*, 1989 who reported correlations of approximately 0.95 for normal subjects and 0.82 for patients.

To further investigate the relationship between EEG and actigraphically recorded sleep duration's, the mean difference in sleep onset and offset between EEG and actigraphy were calculated. The results of this analysis revealed that the difference between EEG and actigraphic sleep onset was between 6.8-20.9 minutes for both groups for all sleep periods (see Table 3), while the difference between EEG and actigraphic sleep offset was between 3.7-9.2 minutes for night-time sleep periods, and between 16-32.9 minutes for the day-time sleep periods. This suggests that for day-time sleep periods actigraphy or alternatively the actigraphic scoring criteria is less able to detect sleep offset. This may be a consequence of the actigraphy being less able compared to EEG to detect quite wakefulness. During a day-time sleep period subjects may spend more time lying in bed awake at the end of the sleep period than at the end of a night-time sleep period.

Sleep efficiency is often used as a measure of sleep quality, based on the principle that the greater the proportion of the sleep period spent awake the poorer the sleep quality. In the current study, electrophysiologically measured sleep efficiency was considered the "gold standard", and was compared to actigraphic movement index. In the past, correlations between EEG and actigraphic sleep efficiencies have been between 0.63 (sleep apnoea patients in Sadeh *et al.*, 1989) and 0.98 (normal subjects, Kripke *et al.*, 1978). However, in the present study correlations between actigraphic and electrophysiological measures of sleep efficiency varied greatly (see Table 4 (a) & (b)). For young subjects the correlation between EEG and actigraphy was high at night (0.72-0.76) and lower during the day (0.15-0.57). However, for older subjects correlations were low for all sleep periods (-0.18-0.58).

To further investigate the discrepancy in the correlation between and within the older and younger subjects, sleep efficiencies were plotted on scattergrams. These scattergrams revealed that for the third night sleep in the older group, there was a very narrow range of sleep efficiency scores. This finding may, in part, account for the lower negative correlation between EEG and actigraphic sleep efficiency for this sleep period. In addition, possible methodological differences in previous studies may account for the discrepancies found in the current study. Specifically, previous studies may have assumed normal distributions of sleep efficiencies and used inappropriate statistics. Few studies have looked directly at the difference in the agreement between EEG and actigraphy between day and night-time sleep periods other than for multiple sleep latency tests (Levine *et al.*, 1986). Therefore, while analysis differences may account for the low night-time correlations in the current study there is nothing comparable for day-time sleep periods.

In previous studies using actigraphy, researchers have typically used algorithms to determine sleep-wake activity. In addition, these algorithms have been used on a variety of different subject groups. We hope to use the results of the current study as a basis to create a new algorithm for use in shiftwork populations. Hopefully by determining the agreement between EEG and actigraphy both during the day and night-time we will be able to more accurately design an algorithm to determine sleep/wake activity in shiftworkers. At the moment, the best alternative to an algorithm for shiftworkers, may be to use the algorithms that are used to score sleep-wake in insomniacs, particularly if recording day-time sleep periods.

Furthermore, while the current study was completed under strict laboratory conditions, in a real-world (field-based) setting other factors should be considered when analysing and using data from activity monitors. For example, the activity monitor is extremely sensitive, and movements from a bed partner may be recorded as wakefulness when the subject is actually asleep (Pankhurst and Horne, 1994). In addition, Sadeh and colleagues (1995), have suggested that activity monitors should always be used in conjunction with sleep diaries, to enable the identification of artefacts.

Taken together the results from this study suggest that actigraphy is a valid and reliable measure of sleep/wake activity in shiftworkers. However, caution should be used in the application of sleep efficiency measures. In addition, age seems to be an important determinant of the correlation between PSG and actigraphically recorded sleep / wake behaviour and should therefore be considered accordingly. It should also be noted that the results of this study are not generalizable to other types of activity monitors or algorithms. Further studies of the effectiveness of activity monitors should be carried out in a field-based setting to identify and quantify factors that may influence the reliability and accuracy of the actigraphic recording of sleep/wake behaviour.

Chapter Four

Age-related differences in sleep under optimal conditions with reduced psycho-social interaction during a simulated 12-hour shift rotation

4.1 Introduction

Under normally entrained conditions non-shiftworkers typically sleep during the night-time hours. Shiftworkers, however, are often attempting to sleep during the day, which often results in shorter day-time compared to night-time sleep durations (Foret and Lantin, 1972; Tilley *et al.*, 1981; Torsvall *et al.*, 1981, 1989; Akerstedt *et al.*, 1991a). In addition, many shiftworkers work extended duty hours (10-16 hours), which are usually performed consecutively within a compressed work week. This means that not only are shiftworkers attempting to sleep at times of low sleep propensity (Lavie, 1986; Folkard and Barton, 1993b; Czeisler *et al.*, 1980) but they often have a limited opportunity to sleep between shifts.

There is no consensus on the effect of 12-hour shifts on sleep duration (review by Duchon and Smith, 1993; Rosa *et al.*, 1989; Kogi *et al.*, 1991; Colligan and Tepas, 1986; Campbell, 1980). Several field-based studies have reported that day-time sleep durations following a night shift are longer than sleep periods following 12-hour day shifts (Budnick *et al.*, 1994; Gillberg, 1997; Rosa *et al.*, 1989; Parkes, 1994; Peacock *et al.*, 1983). In contrast, many other studies have reported reductions in sleep duration and quality of shiftworkers during the day (Rosa, 1991; Frese *et al.*, 1984; Foret and Lantin, 1972; Tilley *et al.*, 1981; Torsvall *et al.*, 1981, 1989; Akerstedt *et al.*, 1991a; Parkes, 1994). There is evidence to suggest that these contrasting findings are at least in part, the result of environmental (e.g. light, noise, temperature) and social or domestic factors. For example, Parkes (1994) investigated the sleep of onshore and offshore oil workers. On the oil rig many environmental and psycho-social factors were reduced compared to conditions for the onshore workers. The sleep of offshore workers during the day-time was longer than night-time sleep durations. In comparison, day-time sleep durations for the onshore workers were shorter than night-time sleep periods.

Another factor that may influence the sleep of shiftworkers is age. As people age there are distinct changes to circadian rhythms and sleep, such that there are reductions in the amplitude and lability of circadian rhythms, and sleep is lighter and more fragmented (Bliwise, 1993; Miles and Dement, 1980; Myers and Badia, 1995). Partly as a result of difficulty in adjusting to circadian disruption (Foret *et al.*, 1981; Harma *et al.*, 1990, 1994; Matsumoto *et al.*, 1987) older shiftworkers often experience significantly greater sleep disruption than younger shiftworkers (Foret *et al.*, 1981; Harma *et al.*, 1990, 1994; Akerstedt and Torsvall, 1981; Parkes, 1994; Parvard *et al.*, 1982). Parkes (1994) reports that age was negatively correlated to sleep duration, but she does not report the degree of the difference in sleep duration or whether both night and day sleep periods are affected.

Under laboratory conditions where environmental and social factors can be controlled it may be possible to determine the influence of these factors on sleep and determine whether this is different for older and younger subjects. The aim of the current study was to investigate the differences in sleep duration and architecture under optimal conditions with reduced psycho-social input between young and older individuals during a simulated 12-hour shift rotation.

4.2 Methods

Subjects

Thirty two subjects participated in this study. Subjects were allocated to groups according to age. Group one had four female and twelve male subjects aged between 18-30 with a mean (± s.d.) age of 21.2 ± 2.7 years, and group two had three females and thirteen male subjects aged between 35-56 with a mean (± s.d.) age of 43.9 ± 6.8 years. All subjects were screened by interview, general health questionnaire and a two week sleep diary. Subjects were excluded if they smoked, were using medication, or had a history of sleep or psychiatric disorders. Shiftwork experience was not recorded.

Procedure

See Figure 1 for a schematic representation of the experimental protocol.

Subjects entered the laboratory at 1700 hours on day-one of the study. Night one was an adaptation night (see procedure in Chapter three). Following the adaptation night subjects underwent a simulated 12-hour shift rotation. During this time they completed two 12-hour day shifts between 0700-1900 hours, followed by two 12-hour night shifts between 1900-0700 hours.

Subjects self selected sleep times, but were awoken approximately one hour before their shift commenced if they did not wake themselves. Each subject had their own room, in which environmental factors such as light (<50 lux with lights on), noise and temperature were controlled. Sleep was recorded using standard polysomnography.

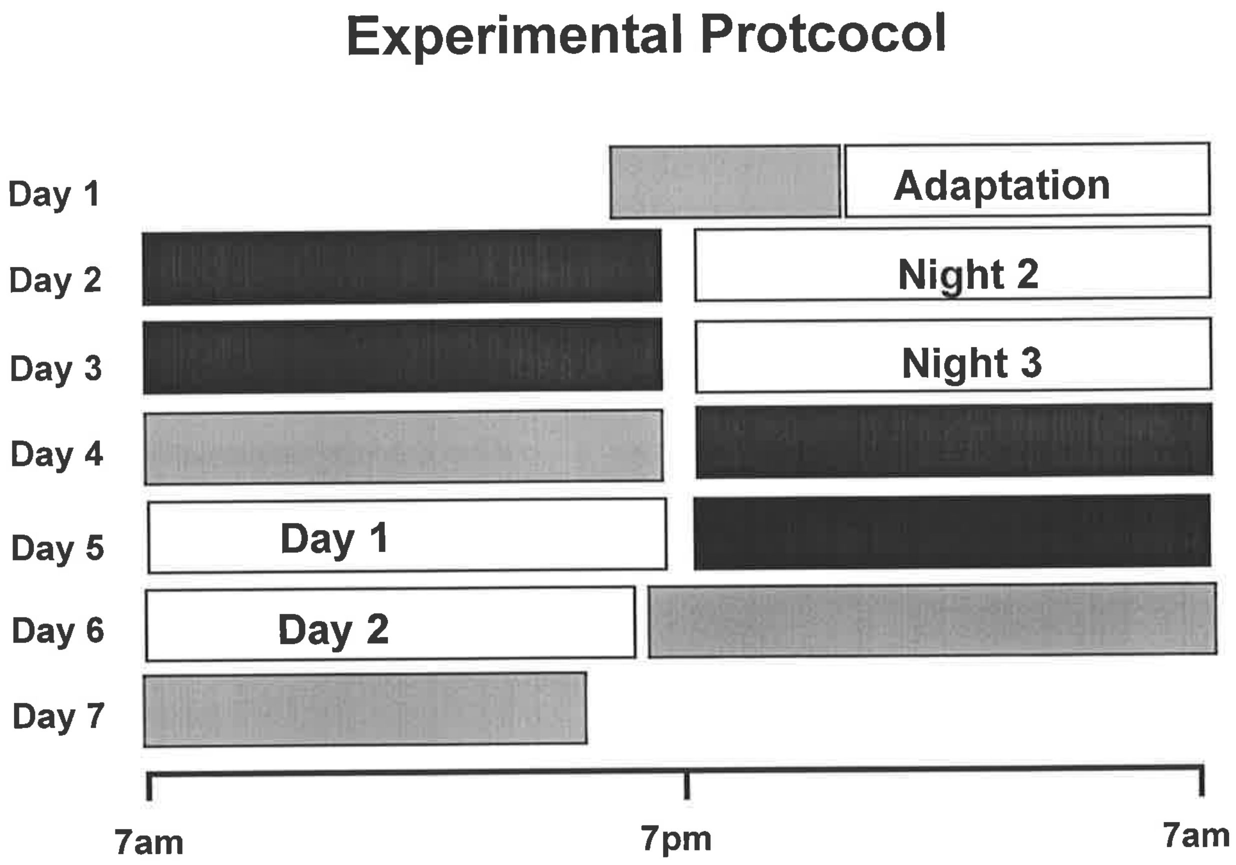


Figure 1. Schematic representation of the experimental protocol. Subjects were wired with a standard electrode montage for all sleep periods (white areas). Night 1 was an adaptation night, followed by sleep period Night 2 and 3, and then Day-time sleep periods 1 and 2. The black areas indicate the 12-hour day or night shifts and the grey area are periods of "free-time".

Sleep Measures

Polysomnography (Oxford SAC)

Sleep stages were determined using standard polysomnography (PSG) collected in 30 second epochs. A standard electrode montage was used with EEG (C3-A2, 02-A1), EOG and EMG. Electrophysiological data were sampled at 500 Hz and stored at 250 Hz using an Oxford sleep analysing computer (SAC-847, Oxford Medical Inc., UK). Electrophysiological data were obtained within a 70 Hz bandwidth, with a low-filter-cut-off of 0.33 Hz. PSG recordings were visually scored in thirty second epochs, according to standard criteria (Rechtschaffen and Kales, 1968).

4.3 Analysis of Results

Sleep variables were compared between, sleep periods (night 2 & 3 and day 1 & 2), time-of-day and age (young and older subjects) using repeated measures ANOVA, and post hoc Bonferroni/Dunn t-tests. The adaptation night (night 1) was excluded from all analysis.

4.4 Results

Sleep duration, sleep efficiency and sleep stages were scored using standard criteria (Rechtschaffen and Kales, 1968), expressed in minutes and are presented in Figure 2.

Sleep Duration

Two measures of sleep duration where determined, Sleep Period Time (sleep onset to early morning awakening) and Total Sleep Time (total minutes of sleep).

Sleep Period Time (SPT)

Repeated measures ANOVA of Sleep Period Time (SPT) for all sleep periods showed a significant main effect for age and sleep period and a significant interaction effect for age and sleep period (see Table 1).

Post hoc t-test analysis revealed that there was no significant difference in SPT between the older and younger subjects for the night-time sleep periods. However, day-time SPT for the older subjects were significantly shorter with a mean (± s.e.m.) 440 (± 25) and 333 (± 23.8) than for the younger subjects 510 (± 35.2) and 394 (± 29.4) respectively (see Figure 2).

SPT on day sleep one for the young subjects was significantly greater 510 minutes (± 35.2) ($p<0.05$) than all other sleep periods. In addition, for the younger group, average SPT for the second day-time sleep period (394 minutes (± 29.4)) was not significantly different from the average night-time sleep periods (394 (± 6.1) and 349 (± 27.2) minutes respectively) (see Figure 2).

In the older group, SPT on day sleep two was significantly shorter with a mean (± s.e.m.) 333 (± 23.8) than all other sleep periods 365 (± 9.8), 391 (± 13.1) (night-time) and 440 (± 25) minutes (day-time) (see Figure 2).

Total Sleep Time (TST)

Repeated measures ANOVA of Total Sleep Time (TST) for all sleep periods revealed a significant main effect for age and sleep period and a significant interaction effect between sleep period and age (see Table 1).

Post hoc t-test analysis indicated that TST during the night-time sleep periods were not significantly different between age groups. In addition, TST for both day-time sleep periods in the older group with a mean (± s.e.m.) 368 minutes (± 19.7) and 259 minutes (± 21.2) were significantly lower compared to TST for day-time sleep periods in the younger group with a mean (± s.e.m.) 451 (± 29.4) and 350 (± 28.2) minutes respectively (see Figure 2).

TST on day sleep one for the young subjects 451 (± 29.4) was significantly greater ($p<0.05$) than all other sleep periods 355 (± 11.8), 322 (± 26.1), and 350 (± 28.2) minutes. In addition, for the younger group, average TST for the second day-time sleep was not significantly different from the night-time sleep periods (see figure 2).

In the older group, TST on day sleep two 259 minutes (± 21.2) was significantly shorter than all other sleep periods 322 (± 11.5) and 349 (± 11.7), and 368 (± 19.7) minutes respectively (see Figure 2).

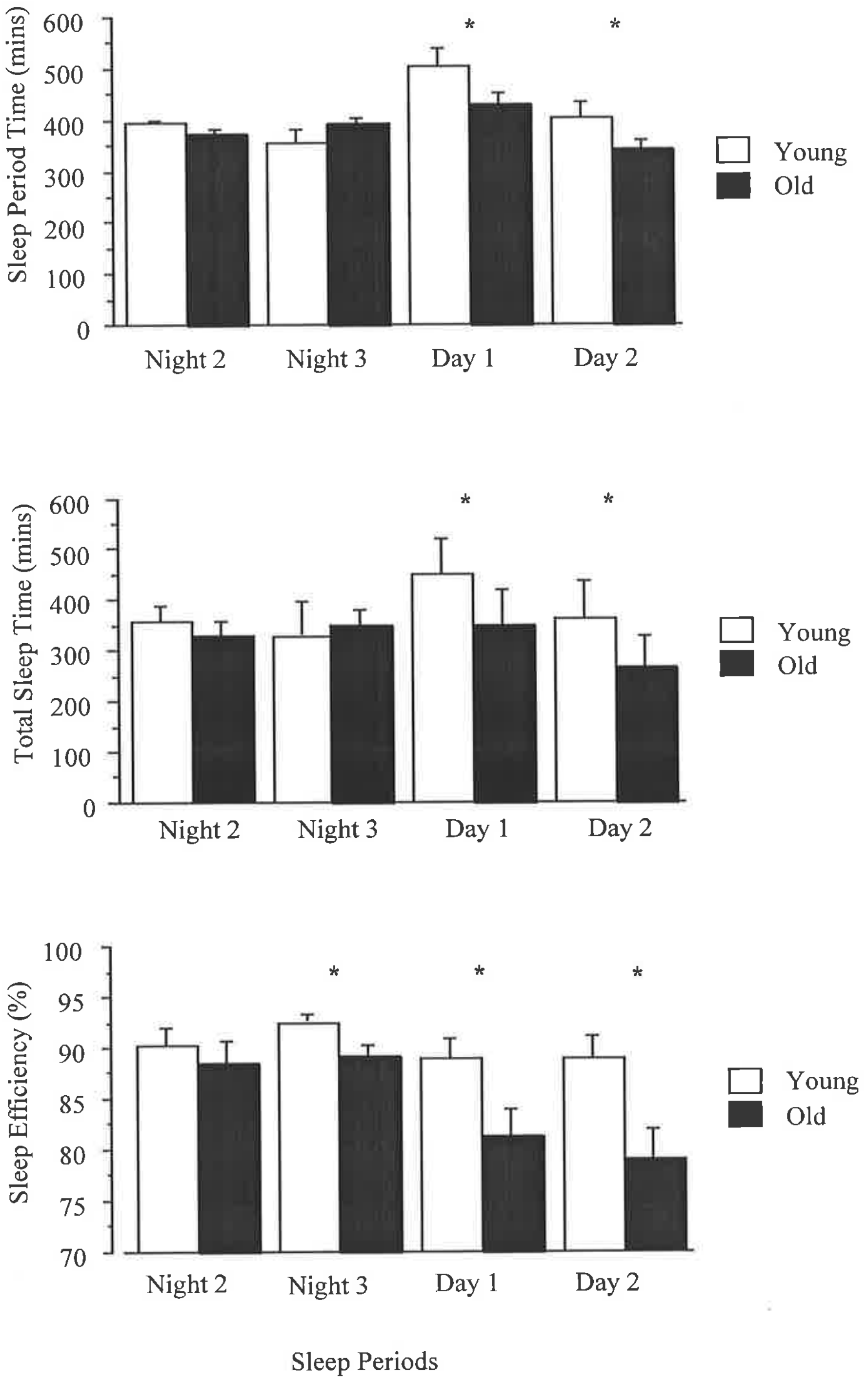


Figure 2. Sleep Period Time (SPT), Total Sleep Time (TST) in minutes and Sleep Efficiency (%) for both day and night-time sleep periods for younger (open boxes) and older (closed boxes) subjects during a simulated 12-hour shift rotation.

Table 1. Repeated measures ANOVA of age (18-30 years & 35-55 years) and sleep period (N1, N2, D1, D2) for all sleep variables in minutes.

	Main				Interaction	
	age F(df)	p	sleep F(df)	p	age x sleep p. F(df)	p
SPT	8.9 (1,16)	0.008	8.9 (3,48)	<0.0001	3.0 (3,48)	0.03
TST	24.2 (1,16)	0.0001	6.1 (3,48)	0.0013	4.1 (3,48)	0.01
S.Eff	12 (1,16)	0.003	6.0 (3,48)	0.001	-	ns
Stage 0	9.4 (1,16)	0.007	5.6 (3,48)	0.002	3.3 (3,48)	0.02
Stage 1	-	ns	3.5 (3,48)	0.02	-	ns
Stage 2	5.9 (1,16)	0.02	3.9 (3,48)	0.01	3.7 (3,48)	0.01
Delta	17.7 (1,16)	0.0007	4.8 (3,48)	0.005	-	ns
REM	-	ns	4.3 (3,48)	0.008	3.6 (3,48)	0.02

Sleep Efficiency

Sleep efficiency was calculated as the TST/SPT and expressed as a percentage (%). Repeated measures ANOVA showed a significant main effect for age and shift (see Table 1).

There was no significant difference in sleep efficiency between the older and younger subjects for the first night-time sleep period. However, sleep efficiency for the older subjects was significantly lower than the younger subjects for night three and both day-time sleep periods (see Figure 2).

Post hoc t-test analysis revealed that, for the younger subjects, sleep efficiency on night three 92% (± 0.7) was significantly greater than on day sleep one 88% (± 2.1) ($p<0.04$), while for the older subjects, sleep efficiencies for the day-time sleep periods 84% (± 2) and 78% (± 3.5) were significantly lower than for the night-time sleep periods 88% (± 2.4) and 89% (± 1.2) ($p<0.02$) respectively (see Figure 2).

Sleep Architecture

Sleep stages were scored using standard criteria (Rechtschaffen and Kales, 1968), expressed in minutes and are presented in Table 2.

Stage 0

Repeated measures ANOVA showed a significant main effect for age and sleep period and a significant interaction effect between age and sleep period (see Table 1).

The older subjects spent significantly more time in stage 0 during the day-time sleep periods than for the night-time sleep periods (see Table 2), and significantly more time in stage 0 than the younger subjects (see Table 3).

Stage 1

Repeated measures ANOVA showed a significant main effect for sleep period (see Table 1).

In the older subjects there was significantly more stage 1 during the day-time sleep periods compared to night 2 sleep period (see Table 2).

Stage 2

Repeated measures ANOVA of stage 2 showed a significant main effect for age and sleep period and a significant interaction effect between age and sleep period (see Table 1).

Post hoc t-test analysis revealed that there was significantly less stage 2 sleep in the older subjects during the day sleep periods compared to the younger subjects (see Table 3). In addition, in the older subjects there was significantly less stage 2 sleep during day sleep 2, than both of the night sleep periods (see Table 2).

Delta (Stage 3 and 4)

Repeated measures ANOVA of delta sleep showed a significant main effect for age and sleep period (see Table 1). On average older subjects had less delta sleep than younger subjects.

Post-hoc t-test analysis revealed that the total minutes of delta sleep per sleep period was reduced in the older subjects compared to the younger subjects in all sleep periods except for night 3 (see Table 3). In addition, in the younger group delta for day sleep 1 was significantly less than delta on night 2 ($p<0.03$) and significantly more than for day sleep 2 ($p<0.02$) (see Table 2).

REM

Repeated measures ANOVA for minutes of REM revealed a main effect for sleep period and an interaction effect for age and sleep period (see Table 1).

Post-hoc t-test analysis revealed that the older subjects had significantly less REM during the second day-time sleep period compared to the younger subjects (see Table 3). In addition, the younger subjects had significantly less REM during the night-time sleep periods compared to the day-time sleep periods ($p<0.05$) (see Table 2).

Table 2. Mean sleep variables in minutes (± s.e.m.) for day and night-time sleep periods following a 12 hour shift rotation, and Post hoc analysis between sleep periods for younger and older subjects.

	Sleep Periods								
	Night 2		Night 3		Day 1		Day 2		Post-hoc
	young	old	young	old	young	old	young	old	
stage 0	29.7 (4.9)	39.5 (9.1)	39.7 (10.9)	37.9 (6.6)	42.1 (13.2)	99.4 (17.8)	40.4 (8.2)	99.5 (20.1)	old N2,N3>D1,2
stage 1	3.8 (0.6)	3.5 (0.7)	3.5 (0.8)	4.2 (1.3)	4.8 (0.7)	4.4 (0.8)	5.6 (1.1)	6.7 (1.7)	old N2<D1, 2
stage 2	172 (7)	155 (9)	144 (13)	154 (14)	188 (15)	133 (13)	155 (17)	103 (11)	old N2,N3>D2
delta 3+4	106 (3.6)	67.1 (7.2)	104.5 (7.3)	79.4 (9)	125.8 (11)	102 (7.8)	96 (8.4)	65.2 ((7.7)	young N2<D1 & D2<D1
REM	78.5 (11)	92.5 (7.4)	72.9 (8.5)	105 (11)	133 (7)	105 (17)	105 (14)	75.8 (7.2)	young N2,3<D1, 2

Table 3. Unpaired t-test results for young versus old subjects for sleep stages in minutes.

Stage	Night 2	Night 3	Day 1	Day 2
0	ns	ns	0.01	0.01
1	ns	ns	ns	ns
2	ns	ns	0.02	0.002
Delta	0.03	ns	0.02	0.0008
REM	ns	ns	ns	0.05

ns= not significant

4.5 Discussion

Sleep Duration

The results of the current study indicate that during a simulated 12-hour shift rotation day-time sleep durations were, in most cases, the same or longer than night-time sleep durations. There were also significant differences in day-time sleep between older and younger subjects. For the younger subjects sleep on day one was significantly longer, and on day two not significantly different from night-time sleep periods. In contrast, for the older subjects day-time sleep one was not significantly different while day sleep two was significantly shorter than all other sleep periods.

Numerous studies of 8 and 12-hour shifts report shorter sleep durations during the day compared to sleep during the night (Foret and Lantin, 1972; Tilley *et al.*, 1981; Torsvall *et al.*, 1981, 1989; Akerstedt *et al.*, 1991a; Rosa, 1991; Frese *et al.*, 1984). In contrast, results of the current study indicate that night-time sleep durations were often the same or longer than day-time sleep durations. In fact all except the second day sleep for the older subjects was the same or significantly greater than night-time sleep durations. TST and SPT for the first day-time sleep period for the younger subjects was approximately 2 hours longer than all other sleep periods, while TST and SPT for the second day-time sleep period was not significantly different than the night-time sleep durations. In contrast, for the older subjects, SPT and TST were approximately 1 hour shorter on day-sleep two (5.5 and 4.3h respectively) compared to all other sleep periods. Therefore, it appears that the younger subjects, and to a lesser degree the older subjects, are able to sleep as long, if not longer, following a 12-hour night shift as following a 12-hour day shift. The results from the current study are similar to field-based studies by Budnick *et al.* (1994), Rosa *et al.* (1989) and Parkes (1994) who reported that in some cases sleep following a 12-hour night shift was significantly longer than following a 12-hour day shift. At least for the Parkes (1994) study this may be the result of reduced psycho-social factors due to the working and living conditions.

Akerstedt and Torsvall (1981) report that the major predictor of sleep length is age, and that only day-time sleep periods were different. Similarly, in the current study there were no significant differences between sleep period time (SPT) or total sleep time (TST), between younger and older subjects for the night-time sleep periods. However, for the older subjects SPT and TST for day-time sleep periods were significantly shorter (approximately 1 hour) compared to the younger subjects. Likewise in a field-based study Parvard *et al.*, (1982) reported that night workers aged 20-30 had a mean sleep length 1.5 hours greater than night workers over 50 years of age.

Although the day-time sleep durations in the current study are longer or the same as the night-time sleep periods all except one sleep duration was shorter (4.3-7.5 hours) than those typically reported for non-shiftworkers (7-9 hours) (Williams *et al.*, 1974; Carskadon and Dement, 1994). This means that on average subjects were sleeping approximately 2 hours less than "normal" regardless of whether they are working a 12-hour night or day shift. Subjects may therefore be experiencing significant cumulative sleep deprivation (Carskadon and Dement, 1981) across the shift rotation. Previous research suggests that this level of sleep loss may lead to significant increases in sleepiness and reductions in performance (Gillberg, 1995; Dinges *et al.*, 1997).

The reductions in night-time sleep compared to habitual and day-time sleep durations may be due to subjects not altering habitual bed times prior to the day shift. This may be because on a 12-hour shift schedule the activities of daily living are compressed into a shorter period between consecutive shifts than is typical for 8-hour schedules (12 Vs

16 hours). In the current study subjects went to bed at the habitual bed time and had approximately 6.5 hours of possible sleep time during the night, during the day subjects had 7-8 hours of possible sleep time (time in bed). Even though subjects spent longer in bed during the day-time, only sleep on the first day-time sleep period for the younger subjects was significantly increased compared to the night-time sleep periods.

The greater duration of day-time sleep one may in part be the result of increased prior hours of wakefulness, rather than circadian factors (Lavie, 1986; Czeisler *et al.*, 1980). It is also unlikely that subjects would have significantly adapted their circadian rhythms to a night shift schedule after only one shift. Previous research suggests that following disruption to circadian rhythms (for example time zone shifts and shiftwork) individuals tend to adjust by approximately one hour per day (Mills, 1976; Wever, 1980). While on average the rate of resynchronization is one hour per day it is exponential rather than linear, with the amount of readaptation reduced by about half for each successive shift depending on the rhythm measured and the direction of shift rotation. The idea of prior hours of wakefulness is further supported by the fact that the second day-time sleep period is significantly shorter than the first for both age groups. Prior to the second day-time sleep period subjects had approximately 14 hours of prior wakefulness, whereas, prior to the first day-time sleep period subjects had approximately 25 hours of prior wakefulness (see chapter 5) and as a result, homeostatic sleep need would have been reduced for the second day sleep period. Alternatively, the second day-time sleep period may have been shorter than the first because subjects knew they did not have to work that night, and therefore, chose to wake earlier to reduce the difficulty in returning to their normal nocturnal sleeping pattern. Similar results have been previously reported by Anderson and Bremer (1987) who suggest that it is possible to obtain an adequate amount of sleep following the first night shift, and that sleep following subsequent night shifts and particularly following the last night shift are shorter (Knauth and Rutenfranz, 1981).

Sleep Architecture

Previously Dement and colleagues (1982) reported that the sleep of the middle-aged and elderly is different from that of the young, and is characterised as being shorter and more easily disrupted, more fragmented and lighter. The same can be used to describe the day sleep of a night worker (Akerstedt, 1985b). During day-time sleep periods stage 2, REM, and sleep latencies are reduced, while stage 3 and 4 are unaltered, and REM periods occur earlier in the sleep period (Akerstedt *et al.*, 1991a). Therefore, while the duration of day-time sleep periods, in the current study, may be longer/shorter or the same they may be of less restorative value. To determine the degree of sleep disruption, sleep efficiency and sleep architecture for all sleep periods was assessed.

In the current study there were significant differences in sleep architecture between sleep periods and between older and younger subjects. Sleep efficiencies for the older subjects were significantly lower during the day-time compared to the night-time sleep periods. In comparison, sleep efficiency for the younger subjects for the first day-time sleep was less than the third night-time sleep. Furthermore, sleep efficiency for the older subjects was on average significantly lower compared to the younger subjects.

Sleep architecture changes were distinctly different between day and night sleep periods for the younger and older subjects. There were significant changes in stages 0, 1, and 2 in the older subjects, while for the younger subjects there was a significant difference in sleep efficiency, delta (stage 3 & 4) and REM sleep. Specifically, the older subjects spent significantly more time in stage 0 during the day-time sleep periods than for the night-time sleep periods. They also spent significantly more time in stage 0 for the day-time sleep periods than the younger subjects. Torsvall and colleagues (1981), reported that day sleep for older shiftworkers included relatively more stage changes, awakenings and stage 1. Similarly, the older subjects in the current study spent more time in stage 1 during the day-time compared to night two and significantly less time during the day in stage 2 sleep compared to younger subjects and compared to night-time sleep periods. In addition, delta sleep (stage 3 & 4) for the older subjects was significantly less than the younger subjects for all except one sleep period (night 3). This is not surprising as older individuals typically have less delta sleep than younger subjects during night-time sleep periods (Dement *et al.*, 1982; Bliwise, 1993, 1994). There were also changes in delta, such that, day sleep one in the younger group, was significantly less than delta on night two and significantly more than for day sleep two. The younger subjects had more minutes of REM during the day compared to the night-time sleep periods and the older subjects had less REM during the second day-time sleep period, compared to the other sleep periods. This is in contrast to results reported by Akerstedt and colleagues (1991a) that REM is reduced during the day and delta is unaffected.

When taken together the results of this study suggest in a laboratory environment, under optimal conditions with reduced psycho-social input, sleep during the day in younger and to some degree older subjects may be as long if not longer than night-time sleep when on a 12-hour shift rotation. In addition, the significant difference in sleep duration between younger and older subjects during the day-time suggests that the older subjects are not able to cope as well as the younger subjects with sleeping out of phase, and/or with the 12-hour compression of the work week. They also suggest that prior hours of wakefulness plays an important part in determining sleep duration. Therefore, it seems that sleep duration and architecture in shiftworkers is influenced by a combination of circadian, homeostatic, age and competing psycho-social factors.

Chapter Five

Comparing performance on a simulated 12-hour shift rotation in young and older subjects

5.1 Introduction

Significant reductions in neuro-behavioural performance during shiftwork and particularly night work have long been recognised (Browne, 1949; Bjerner and Swennson 1953; Daniel and Potasova, 1989). These reductions in performance are thought to be the result of both the sleep disruption associated with shiftwork (Tilley *et al.*, 1982) and the circadian rhythm of performance (Folkard *et al.*, 1985; Colquhoun, 1981). Research has linked the increase in sleepiness and reductions in performance associated with night work with an increase in accidents that are estimated to cost industry and the community billions of dollars each year (Leger *et al.* 1994, Mitler *et al.* 1988).

With increasing industry demands shiftwork and the variety of different shiftwork schedules is increasing. For some industries a popular alternative to the typical 5/7 x 8 hour rotating work week is the 4/8 x 12-hour shift rotation (Colligan and Tepas, 1986; Duchon *et al.*, 1994). The benefits resulting from this type of schedule are numerous. Typically, these include a reduction in the number of shifts and staff required each day, and an increased amount of time off by compressing the working week (Rosa *et al.*, 1993). However, there are conflicting reports of the effects of extended hours of work on performance, alertness and safety (Budnick *et al.*, 1994; Tucker *et al.*, 1996; review by Duchon and Smith, 1993; Rosa *et al.*, 1989; Kogi *et al.*, 1991; Colligan and Tepas, 1986; Campbell, 1980; Rosa *et al.*, 1988).

Previous research has shown that the ability to adapt to shiftwork is more difficult for those over the age of 40 (Foret *et al.*, 1981; Harma *et al.*, 1990; Matsumoto *et al.*, 1987). Specifically, older shiftworkers experience an increase in sleep disruption (Foret *et al.*, 1981; Akerstedt and Torsvall, 1981; Parkes, 1994; Parvard *et al.*, 1982), and a reduction in the ability of circadian rhythms to readjust to new schedules (Harma, 1990). However, there is little literature on whether the increased sleep disruption in older shiftworkers results in subsequent performance deficits, above those typically reported (Tilley *et al.*, 1982). Sleep deprivation studies in young and middle aged subjects have been inconclusive. Webb and Agnew (1974) found that older individuals were more sensitive to performance impairment following sleep deprivation. However, Bonnet and Rosa (1987) report a similar degree of performance impairment in younger and older subjects following sleep deprivation. Furthermore, studies of performance following sleep disruption have shown that while both young (20's) and old (60-80's) subjects are sensitive to sleep disruption, the older subjects are slightly less sensitive to the effects than the young (Bonnet, 1989, Brendel *et al.*, 1990). However, some caution needs to be used, as performance following 60 hours of sleep deprivation, and sleep disruption studies in eighty year olds may have little relevance to the on the job performance of a 40-60 year old shiftworker.

Inconclusive evidence suggests that performance in older subjects is significantly different from young subjects following sleep loss or disruption (Bonnet and Rosa, 1987; Webb and Agnew, 1974; Bonnet, 1989, Brendel *et al.*, 1990). There are conflicting reports on whether performance is significantly reduced during 12-hour shifts above that reported for 8-hour shifts at the same time-of-day (Budnick *et al.*, 1994; Duchon and Smith, 1993; Rosa *et al.*, 1989). The combined effect of 12-hour shifts and the older worker may result in greater reductions in performance when compared to younger co-workers. If this is the case then there may be serious implications for worker productivity and safety. Considering the increase in the number of older shiftworkers currently employed and the prediction that this will continue to increase in the future (Australian Bureau of Statistics, 1993; 1997) it is important to understand whether performance during a 12-hour shift rotation is reduced, and if this reduction is significantly different in older and younger workers. Hence the aim of the current study was to compare the effects of a simulated 12-hour shift rotation on neurobehavioural performance, in younger and older individuals.

5.2 Methods

Subjects

Thirty two subjects participated in this study. Subjects were allocated to groups according to age. Group one had four female and twelve male subjects aged between 18-30 with a mean (± s.d.) age of 21.2 ± 2.7 years, and group two had three females and thirteen male subjects aged between 35-56 with a mean (± s.d.) age of 43.9 ± 6.8 years. All subjects were screened by interview, general health questionnaire and a two week sleep diary. Subjects were excluded if they smoked, were using medication, or had a history of sleep or psychiatric disorders. Shiftwork experience was not recorded.

Procedure

See Figure 1, for a schematic representation of the experimental protocol.

Subjects came into the laboratory the night before the first day shift, and completed a training session of 40 trials on a neuro-behavioural performance test. In an earlier protocol 40 trials was determined to be sufficient to successfully learn the task (see chapter 2). In addition, the first night sleep was disturbed at hourly intervals from 1800-0300 hours for saliva collection (see method chapter 3).

On the first morning, following the training session, subjects began a simulated 12-hour shift rotation. Over four consecutive days subjects completed two 12-hour day shifts between 0700-1900 hours, followed by two 12-hour night shifts between 1900-0700 hour (see Figure 1). During the work periods subjects carried out simple clerical tasks and a series of three one minute neuro-behavioural performance tests every hour.

Subjects slept in the laboratory for the six days of the protocol. Prior to each sleep period subjects were wired for standard polysomnographic sleep recording.

Equipment

Neuro-Behavioural Performance

Cognitive psychomotor performance was measured using the Occupational Safety Performance Assessment Test (OSPAT) the same task that was used in Chapter two for the alcohol and sustained wakefulness conditions. The OSPAT is an unpredictable tracking task that subjects perform on a computer workstation. In simple terms, the task required subjects to keep a randomly moving cursor in the centre of three concentric circles, using a standard trackball. After the cursor is 'centred' the cursor moves to a random position away from the centre and the subject is required to 're-centre' the cursor. Subjects were seated in front of the workstation in an isolated room, free of distraction and were instructed to manipulate the track-ball using their dominant hand. Subjects completed three one-minute tests in each testing session and received no feedback between tests in order to avoid the knowledge of results affecting performance levels.

A global performance measure for each test is determined by summing the 'error' distance between the cursor and target and the rate at which the subject adapted to the random changes. This measure indicates how "well" the subject performed the task.

Sleep Polysomnography (Oxford SAC)

Sleep stages were determined using standard polysomnography (PSG) collected in 30 second epochs. A standard electrode montage was used with EEG (C3-A2, 02-A1), EOG and EMG. Electrophysiological data were sampled at 500 Hz and stored at 250 Hz using an Oxford sleep analysing computer (SAC-847, Oxford Medical Inc., UK). Electrophysiological data were obtained within a 70 Hz bandwidth, with a low-filter-cut-off of 0.33 Hz. PSG recordings were visually scored in thirty second epochs, according to standard criteria (Rechtschaffen and Kales, 1968).

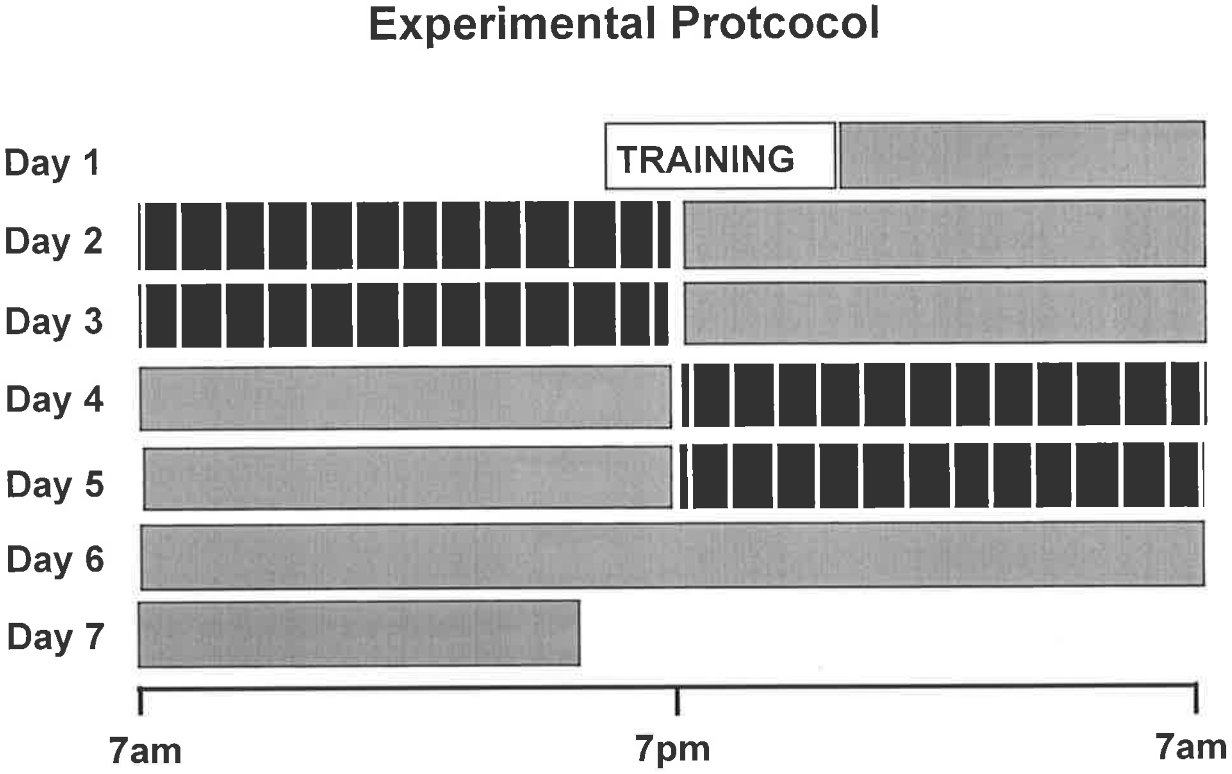


Figure 1. Schematic representation of the experimental protocol. On entering the laboratory on day 1 subjects completed a training session (white area) on the performance task prior to going to bed. On day 2 of the study subjects began a 12-hour shift rotation with two 12-hour day shifts followed by two 12-hour night shifts (black area). Prior to each shift subjects completed a series of 9 practice tests. During the work periods subjects completed hourly performance testing (white bars) between 0700-1900 hours, and 1900-0700 hours.

5.3 Analysis of Results

Each hourly testing session involved three one-minute tests. The average of all three tests was considered one trial for analysis. Repeated measures ANOVA, t-tests (paired and unpaired) and simple regression analysis were used in this study. For analysis neuro-behavioural performance was grouped by shift (day or night), order (first or second), trials (1-13) and age (young and old).

5.4 Results

Neuro-Behavioural Performance

Mean performance for both the young and older group, for each trial on both the day and night shifts can be seen in Figure 2.

Younger Subjects

Repeated measures ANOVA revealed that there was no significant main effect of shifts (night or day shift) or trials (1-13) in the younger subjects. However, there was a significant main effect for order in the night shifts (F (1, 12)=4.7, $p<0.05$). On average mean performance on the first night shift was significantly lower than the second night shift.

Older subjects

Repeated measures ANOVA revealed that there was no significant main effect for shift (day or night shift) in the older subjects. However, there was a significant main effect for trials in both the day, (F (12, 84)=2.1, $p<0.02$) and night shifts (F (12, 144)=3.7, $p<0.0001$). Furthermore, a significant main effect for order was found for the night shifts (F (1,12)=5.05, $p<0.04$). Mean performance on the first night shift was, on average, significantly lower than the second night shift.

In addition repeated measures ANOVA revealed a significant interaction effect for shift and trials in the older group (F (1,12)=2.9, $p<0.002$) see Figure 2.

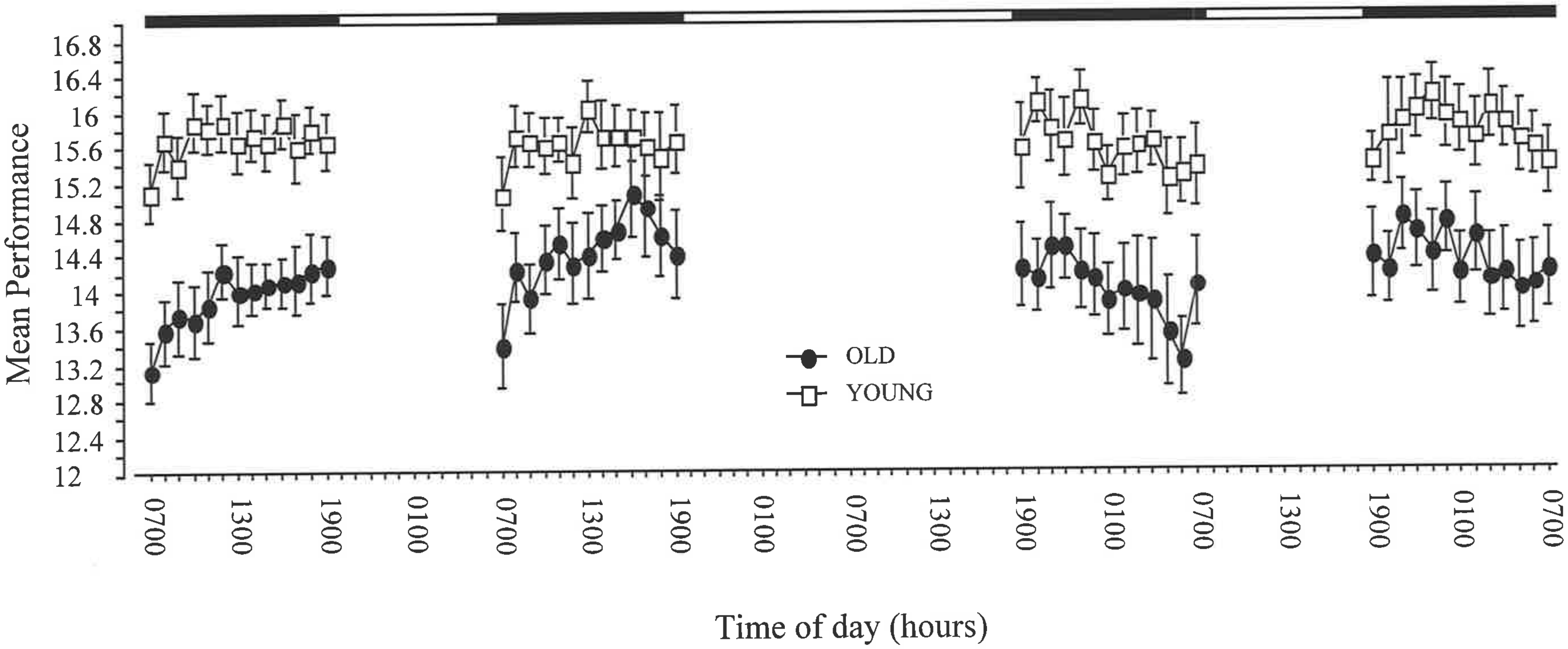


Figure 2. Mean (± s.e.m.) performance at hourly intervals across each 12-hour day and night shift (black bar) for both younger (open squares) and older (closed circles) subjects. White bar indicates time off between shifts.

Younger versus Older subjects

Bonferroni/Dunn t-test revealed that the mean performance in the older subjects was significantly lower than the younger subjects for all shifts ($p<0.0001$) see Table 1.

Table 1. Mean performance (± s.e.m.) for each shift for the young and older subjects.

	Day Shift 1	Day Shift 2	Night Shift 1	Night Shift 2
Young	15.68 (0.08)	15.64 (0.09)	15.62 (0.1)	15.8 (0.1)
Older	13.94 (0.9)	14.38 (0.1)	14.03 (0.1)	14.35 (0.1)
Young Vs Older	*	*	*	*

* = $p<0.0001$

Regression

Simple linear regression for each shift, for both older and younger subjects, can be seen in Table 2.

Linear regression revealed a positive correlation for both day shifts and a negative correlation for both night shifts in both groups. In addition, time-of-trial explained more of the variance in the older group (31%-75%) than in the younger group (6%-43%).

Table 2. Simple Linear Regression analysis (R^2) of mean performance for each shift in the young and older subjects.

	Day Shift 1	Day Shift 2	Night Shift 1	Night Shift 2
Young	0.17	0.08	-0.43 *	-0.06
Older	0.75 *	0.54 *	-0.54 *	-0.31 *

* = $p<0.05$

From the regression equation the percentage change in performance across the shift was calculated and is presented in Table 3. This analysis revealed that there was a greater percentage change in performance across the shifts in older subjects compared to the younger subjects.

Table 3. Percentage change in performance between trial 1 and 13 for each shift.

	Day Shift 1	Day Shift 2	Night Shift 1	Night Shift 2
Young	1.9%	1.4%	-3.84%	-1.22%
Older	7.13%	7.5%	-5.86%	-3.47%

Sleep

Table 4 shows (a) Total Sleep Time (TST) and (b) Hours of Wakefulness (HW) prior to each shift.

There was no significant difference between young and older subjects for TST for night-time sleep periods prior to day shift one and two. However, prior to the second night shift TST in the older subjects was significantly shorter than the younger subjects ($p<0.002$) (see Table 4a).

There was no significant correlation (Pearson r) between prior sleep duration (TST) and mean performance.

Hours of Prior Wakefulness

There was no significant difference between younger and older subjects for hours of wakefulness prior to the shift. However there was a significant difference between shifts. Wakefulness prior to the day shifts was approximately 50 minutes, prior to the first night shift 12.5 hours and prior to the second night shift 3.0 hours ($p<0.05$) (see Table 4b).

Table 4. (a) Total Sleep Time (mean hours and minutes ± s.d) prior to day and night shifts, (b) Hours of wakefulness prior to start of shift (mean hours and minutes ± s.d.). * indicates significant difference within groups between sleep periods ($p<0.05$).

(a)

Total Sleep Time	Day Shift 1	Day Shift 2	Night Shift 1	Night Shift 2
Young	4.17(1.3)	5.9(0.44)	5.3(0.59)	7.5(1.0)*
Older	4.3(0.41)	5.3(0.37)	5.8(0.33)	6.1(1.02)
Young Vs Older	ns	ns	ns	p<0.002

* = $p<0.05$

(b)

Prior Hrs awake	Day Shift 1	Day Shift 2	Night Shift 1	Night Shift 2
Young	0.50 (0.2)	0.55 (0.3)	12.43 (0.19)*	2.17 (1.8)*
Older	0.57 (0.5)	0.57 (0.8)	12.48 (0.23)*	3.09 (1.10)*
Young Vs Older	ns	ns	ns	ns

* = $p<0.05$

5.5 Discussion

This study aimed to determine whether performance differed significantly across a simulated 12-hour shift rotation, and whether this change was different for younger and older subjects. The results of this study indicate that, on average there was no significant difference in mean performance between 12-hour day and night shifts. There was, however, a significant difference in mean performance, and a difference in the pattern of performance across shifts between young and older subjects and for day and night-time shifts during a simulated 12-hour shift rotation.

Performance for the older subjects was approximately 1.8 points lower than the score recorded for the younger subjects. In addition, the pattern of performance differed significantly across trials in the older compared to younger subjects. Repeated measures ANOVA revealed that performance for the younger subjects remained relatively constant across shifts. In contrast, mean performance in the older group changed significantly across both 12-hour day and night shifts.

To investigate the relationship between time-of-trial and performance, a simple linear regression analysis was calculated for all shifts. The results of this analysis revealed that for the older subjects, time-of-trial explained more of the variance in performance (31%-75%) than for the younger subjects (6%-43%). Furthermore, there was a positive correlation for performance during the day shifts and a negative correlation for performance during the night shifts in both groups. In simple terms performance particularly for the older subjects improved across the day shifts and decreased across the night shifts.

From the linear regression the change in performance across shifts was calculated and expressed as a percentage. The results of this analysis revealed that the change in performance across the shift for the younger subjects was 1.4% and 1.9% (increase) during the day shifts and –3.84% and –1.22% (decrease) during the night shifts. In contrast, for the older subjects the change in performance across the shift was 7.13% and 7.5% (increase) during the day shifts and –5.86% and –3.47% (decrease) during the night shifts. The rate of change in performance during the day in the older subjects is greater than for the night shifts and all shifts for the younger subjects. For the older subjects the percentage change in performance was greater than for the younger subjects, suggesting that the older subjects are less able to cope with a 12-hour shift than the younger subjects. Or alternatively it may be that the older subjects are more sensitive to time-of-day effects on performance than the younger subjects.

The results of this study clearly show that performance during the early hours of the morning is reduced compared to later in the day, whether at the beginning or end of a shift, particularly in the older subjects. It has been well established that performance displays a distinct circadian rhythm, with performance on many tasks at a low at in the early hours of the morning (Folkard *et al.*, 1985; Colquhoun, 1981). Interestingly, performance during the early hours of the morning in the younger subjects was not reduced to the same degree as in the older subjects. However, there was a similar degree of sleep disruption in the younger and older subjects on the night shifts, and the older subjects slept less following the night shifts. This suggests that older subjects may be more sensitive to the effects of time-of-day, and sleep disruption than the younger subjects.

Performance was not only significantly different across shifts, but also differed significantly between the two night shifts. In both the young and older subjects, performance on night shift one, was on average, significantly worse than on night shift two. Similarly, Tilley *et al.* (1981), reported that for 8-hour shifts simple reaction time performance on the second morning and night shift was significantly less (i.e. better) than on the first shift in a group of subjects aged between 29-52 (mean 42 years). The greater reduction in performance on night shift one compared to night shift two, may be the result of several factors: time-of-day, extended hours of wakefulness and reduced sleep duration prior to the shift. All subjects (young and old) woke on average at 0615 hours on the morning prior to the first night shift and did not nap during the day, although the opportunity was available. This is similar to the findings of Knauth and Rutenfranz (1981) that report that 50% of workers do not sleep prior to the first night shift. This means that at the start of the first night shift subjects had been awake for approximately 13 hours, and by the end of the shift they had been awake for 25 hours. In contrast, prior to the second night shift subjects had been awake for approximately 2.5 hours. Prior sleep duration also varied between night shifts, subjects slept approximately 5.5 hours the night before the first night shift, but prior to the second night shift they slept on average 6.1 hours in the old group and 7.5 hours in the young group (see Table 1 (a) and (b)). The correlation between sleep duration and performance was not significant, and the correlation for prior hours of wakefulness and performance was primarily due to the influence of time-of-day. With increasing hours of prior wakefulness during the day shifts performance increased and during the night shift performance decreased.

Performance for the first night shift in the younger group did not significantly differ from the day shifts. However, the pattern of performance across night shift one in the younger subjects is significantly different from the other three shifts, that is performance on night shift one resembles the pattern of performance observed in the older subjects. In contrast, the pattern of performance on the first night shift did not significantly differ from the first day shift for the older subjects.

In contrast, to the significant differences in performance observed between consecutive shifts in the older and younger subjects in this study, Harma *et al.* (1994) did not report a significant difference in alertness between older and younger subjects until the 3rd and 4th consecutive 8-hour night shift. In the current study performance was consistently worse in the older subjects compared to the younger subjects for all shifts. This discrepancy between the studies is possibly because Harma *et al.* (1994) used subjective measures of alertness. Rosa *et al.* (1993) reported that on average performance over 2 consecutive 12-hour day-shifts was the same, but that performance was significantly reduced by the third and fourth shift. From these studies it appears that significant differences in performance may not become apparent until the third or fourth shift, possibly due to the cumulative sleep debt accumulated over successive days or to the type of test used. Rosa *et al.* (1993) used different performance tasks to that used in the current study. They used a short mental arithmetic task a dual task consisting of grammatical reasoning combined with auditory reaction time, simple auditory reaction time and hand steadiness.

It is also important to note that subjects in this study were tested under laboratory conditions for only one shift rotation. In a real world setting over an extended period, performance decrements may differ. In addition, the younger subjects in this experiment slept reasonably well (see Chapter 4) which may also account for the difference between this and other studies. If their sleep had been impaired further we may have seen significant reductions in performance. Foret *et al.* (1981) have shown that with increasing age and years of shiftwork there is a significant reduction in the ability to adjust to shiftwork. As a result of these findings there has been some criticism about inexperienced (shiftwork) subjects being used as subjects in shiftwork experiments. Further research is required to investigate the effects of a 12-hour shift rotation in a field-based setting to determine whether performance levels are maintained and to ensure that workers safety is not compromised. It may be that significant reductions in sleep are needed before performance is significantly reduced. Therefore, age or competing social or domestic activities may play more of a role in a real world setting.

In summary, older subjects demonstrate a reduction in performance when compared to younger subjects. There is no significant difference in performance between day and night shifts, but there is a positive correlation or increase in performance across the day shifts and a negative correlation or decrease in performance across the night shifts. This can be seen as a reduction in performance in the early hours of the morning, in the older and to a lesser degree in the younger subjects. We conclude, therefore, that the older subjects are more sensitive to time-of-day and/or sleep disruption.

Experimental Section Three

Chapter Six

Sleep of train drivers working irregular shift schedules

6.1 Introduction

The most commonly reported physical complaint of shiftworkers is sleep disruption (Akerstedt, 1995b). There are numerous studies reporting reductions in the duration (1-2 hours) and quality of sleep, particularly following the night shift and prior to early morning shifts (Folkard *et al.*, 1993b; Frese *et al.*, 1994; Foret *et al.*, 1981; Akerstedt and Torsvall, 1981). Typically these reductions are thought to be the result of sleeping at a time in the circadian cycle that is not conducive for good sleep, as well as not altering habitual bed time prior to early morning shifts (Lavie, 1986; Akerstedt *et al.*, 1992; Folkard and Barton, 1993b; Czeisler *et al.*, 1980).

Previous studies primarily examine the duration and quality of sleep, and report that sleep duration varies as a function of sleep onset time (Foret *et al.*, 1972; Kogi, 1985). There are, however, a few studies on either permanent night or rotating shiftworkers that report the distribution of sleep across the twenty four hour day (Folkard *et al.*, 1978; Knauth *et al.*, 1983; Tepas *et al.*, 1993). From these and other studies we know that on days off shiftworkers often catch-up on sleep and/or revert to their normal sleep-wake pattern (Tepas *et al.*, 1990; Knauth *et al.*, 1980). So, while we know that sleep duration and quality vary depending on when sleep is initiated during the day we do not have a clear record of when irregular shiftworkers choose to sleep.

Other than shift schedule, there are various factors that may influence when shiftworkers sleep during the 24-hour day. These include physiological and psycho-social factors for example, age, morning-eveningness, and domestic status (marital status, young children) (Folkard *et al.*, 1978; Breithaupt *et al.*, 1978, Walker, 1985). Shiftworkers above 40 years of age often experience greater sleep disruption than their younger counterparts (Foret *et al.*, 1981; Tepas *et al.*, 1993; Pavard *et al.*, 1982), and competing demands from work, family and friends may mean that sleep is curtailed. However, the influence of these factors on the timing of sleep-wake patterns of irregular shiftworkers has not been comprehensively studied.

The aim of the current study was to investigate the timing of sleep across the 24 hour day of engine drivers working irregular schedules, and to determine the influence of individual and demographic factors. To achieve this the self-reported sleep of train drivers on an irregular schedule was recorded and the pattern of sleep as a function of time-of-day, age, morning-eveningness type and domestic status was investigated.

6.2 Methods

Subjects

Two hundred and fifty three train drivers with a mean (± std) age 39.7 (± 6.8) (ranged between 25-59 years) gave informed consent to participate in this study for two consecutive weeks. During the study drivers completed daily sleep and work diaries which were used for analysis. This was part of a larger study in which drivers wore wrist activity monitors, completed performance tasks at the beginning and end of each shift and collected urine samples across the major sleep period for latter analysis for the melatonin metabolite 6-sulphatoxy melatonin. Due to the sheer amount of information collected in this larger study it is only within the scope of this thesis to report the self-reported sleep of the 253 drivers involved.

Procedure

In order to select representative working conditions from throughout the rail industry 14 rail depots were selected following consultation with the rail industry and unions. Both passenger (suburban and country including interstate), and freight driving (short and long haul) were represented.

Official rostered hours of work within depots varied between 6-12 hours in length. The range of shifts recorded by drivers, however, was between 2-30 hours. Due to differing rostering methods across and within organisations drivers were given from 12 hours to 2 weeks notice of their shifts. Alterations to work schedules at short notice were a common occurrence, with as little as 2-4 hours notice of changes given.

Shiftwork within the Australian rail industry was classified as irregular. The degree of irregularity is illustrated in Figure 1 (a and b) which depicts a representative two week work and sleep schedule for a driver from (a) a passenger and (b) a freight depot.

Sleep/Wake Diary

Train drivers completed a daily sleep diary, recording all sleep periods including awakenings. Drivers were instructed to fill in diaries directly upon waking, to ensure more accurate recall of sleep. Subjects were asked to rate the quality of their sleep on a scale from 1-5. A score of one was rated "a good sleep" and a score of five "a poor sleep". Subjects were also asked to rate how sleepy or awake they felt before going to sleep and when they woke up using the 7 point Stanford Sleepiness Scale (SSS).

Although there are limitations with self-report methods of sleep/wake behaviour there are also advantages both of which are discussed in more detail in chapter one.

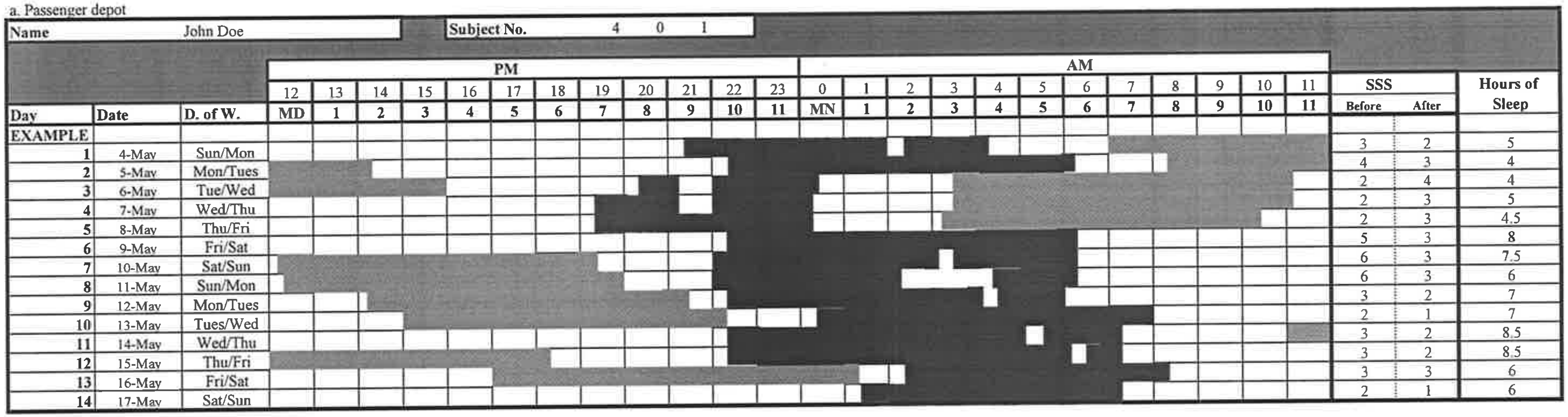
Work diary

Drivers kept a diary of their work times. This included both the start and finish time of the shift. In addition, drivers identified the type of work that each shift involved, which was typically recorded as a code unique to each depot.

Standard Shiftwork Index

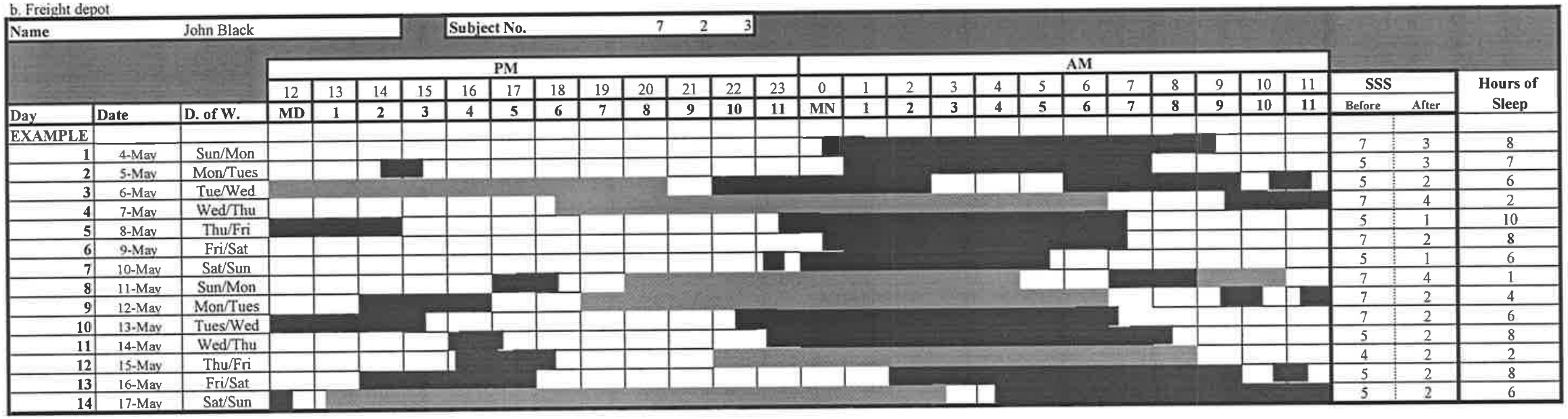
Additional personal information was collected from all drivers, with each driver completing a Standard Shiftwork Index (SSI) (Barton *et al.* 1990). From this survey, information concerning age, marital status, number and ages of children, years of shiftwork, and composite morning-eveningness type (Smith *et al.* 1989) were obtained.

a. Passenger depot



Name	John Doe	Subject No.	4 0 1		
Day	**Date**	**D. of W.**	**SSS Before**	**SSS After**	**Hours of Sleep**
EXAMPLE					
1	4-May	Sun/Mon	3	2	5
2	5-May	Mon/Tues	4	3	4
3	6-May	Tue/Wed	2	4	4
4	7-May	Wed/Thu	2	3	5
5	8-May	Thu/Fri	2	3	4.5
6	9-May	Fri/Sat	5	3	8
7	10-May	Sat/Sun	6	3	7.5
8	11-May	Sun/Mon	6	3	6
9	12-May	Mon/Tues	3	2	7
10	13-May	Tues/Wed	2	1	7
11	14-May	Wed/Thu	3	2	8.5
12	15-May	Thu/Fri	3	2	8.5
13	16-May	Fri/Sat	3	3	6
14	17-May	Sat/Sun	2	1	6

b. Freight depot



Name	John Black	Subject No.	7 2 3		
Day	**Date**	**D. of W.**	**SSS Before**	**SSS After**	**Hours of Sleep**
EXAMPLE					
1	4-May	Sun/Mon	7	3	8
2	5-May	Mon/Tues	5	3	7
3	6-May	Tue/Wed	5	2	6
4	7-May	Wed/Thu	7	4	2
5	8-May	Thu/Fri	5	1	10
6	9-May	Fri/Sat	7	2	8
7	10-May	Sat/Sun	5	1	6
8	11-May	Sun/Mon	7	4	1
9	12-May	Mon/Tues	7	2	4
10	13-May	Tues/Wed	7	2	6
11	14-May	Wed/Thu	5	2	8
12	15-May	Thu/Fri	4	2	2
13	16-May	Fri/Sat	5	2	8
14	17-May	Sat/Sun	5	2	6

Figure 1. Representative sleep diary from (a) passenger train depot and (b) a freight depot. The black bars indicate sleep and the grey bars indicate work.

6.3 Analysis of Results

From the two week sleep and work diary a graph with 24, 1-hour epochs representing an average day was generated for each driver. These graphs indicate the probability that a driver was working, sleeping or involved in other activities for each hour of an average day. In addition, the influence of various work (day on/day off, and shift type), age and domestic factors on sleep-wake were compared.

A "Day On" was defined as the 24 hour period following the of end of a shift, when the next shift began less than 24 hours later, while a "Day Off" was defined as the 24 hour period following the of end of a shift, when the next shift began more than 24 hours later.

Each driver was allocated to a group for predominant shift type. A predominantly morning shiftworker was when 50% or more of the work during the two week test period occurred between 0500-1300 hours, a predominantly afternoon shiftworker was when 50% or more of the work occurred between 1300-2100 hours, a predominantly night shiftworker was when 50% or more of the work occurred between 2100-0500 hours and a predominantly mixed worker was when less than 50 % of work was in one of the previous groups. Shift types were determined in this manner because within the Australian rail industry shifts are very irregular and it is therefore difficult to "pigeon hole" drivers into a particular shift type. For this reason the scope of times covered in each category is quite broad.

From the information collected in the SSI the drivers were allocated to groups according to Age (below 40 years of age/40 years and above), and whether they were living with partner (yes/no), and whether there was young children (<12 years) in the house (yes/no). When drivers were not allocated to a group it meant that the relevant information was missing, for example, they may have failed to fill out the SSI.

In the current study repeated measures analysis of variance (ANOVA) was used to examine the main effects of time-of-day, day on/day off, shift type, age, and driver domestic status on sleep, and the interaction effects between these factors.

6.4 Results

The results of the following groups were considered, combined (all subjects), each shift type, day on / day off, day on / day off for each shift type, age, morning-eveningness type, living with partner and presence of young children in the household. Drivers that could not be placed into one of these categories, due to missing data, were removed from the analysis (see Table 1 and 2 for number of drivers and amount of sleep).

Table 1. The number of drivers and amount of sleep per average day (mean ± s.e.m.) for: all drivers, all drivers day on and off, and predominantly morning, afternoon, night and mixed shift types combined (com) and for day on and off.

	# of Drivers	Hour of Sleep per day
Combined	253	7.6 (0.04)
Day on		7.1 (0.07)
Day off		8.4 (0.07)
Shift Type		
Morning Shift (com)	74	7.3 (0.8)
day on		6.6 (0.09)
day off		8.3 (0.14)
Afternoon Shift (com)	64	7.7 (0.07)
day on		7.4 (0.12)
day off		8.1 (0.14)
Night Shift (com)	16	7.9 (0.2)
day on		7.3 (0.21)
day off		8.9 (0.28)
Mixed Shift (com)	96	7.83 (0/07)
day on		7.1 (0.09)
day off		8.4 (0.09)

Time of day had a significant main effect on the propensity for sleep in all analyes ($p<0.0001$), with most sleep occurring during the night (2200-0800 hours) peaking in the early morning at approximately 0200 hours, and the least sleep occurring during the day (1000-2000 hours) reaching a low in the early evening at about 1900 hours.

Work Schedule

Combined

Figure 2 represents the average sleep and work pattern for all 253 drivers over the 14-day study period. It clearly indicates that the probability of a driver sleeping is highest during the night-time hours (2200-0800 hours).

Shift Type

Repeated measures ANOVA revealed a significant main effect for predominant shift type ($F(3, 1840)=7.09$, $p<0.0001$) and time-of-day ($F(23, 23)=7.56$, $p<0.0001$) on sleep. In addition, there was a significant interaction effect ($F(69, 42320)=13.27$, $p<0.0001$) between these factors.

Mean amount of sleep per day (± s.e.m.) and the number of drivers in each shift type can be seen in Table 1.

Figure 3 depicts the proportion of an average day spent sleeping and working for drivers working shift schedules that are either predominantly afternoon, morning, night or mixed. All drivers, regardless of shift type slept proportionally more during the night-time compared to the day-time. However, a greater proportion of drivers slept during the day-time when on night or mixed shifts compared to the afternoon shifts.

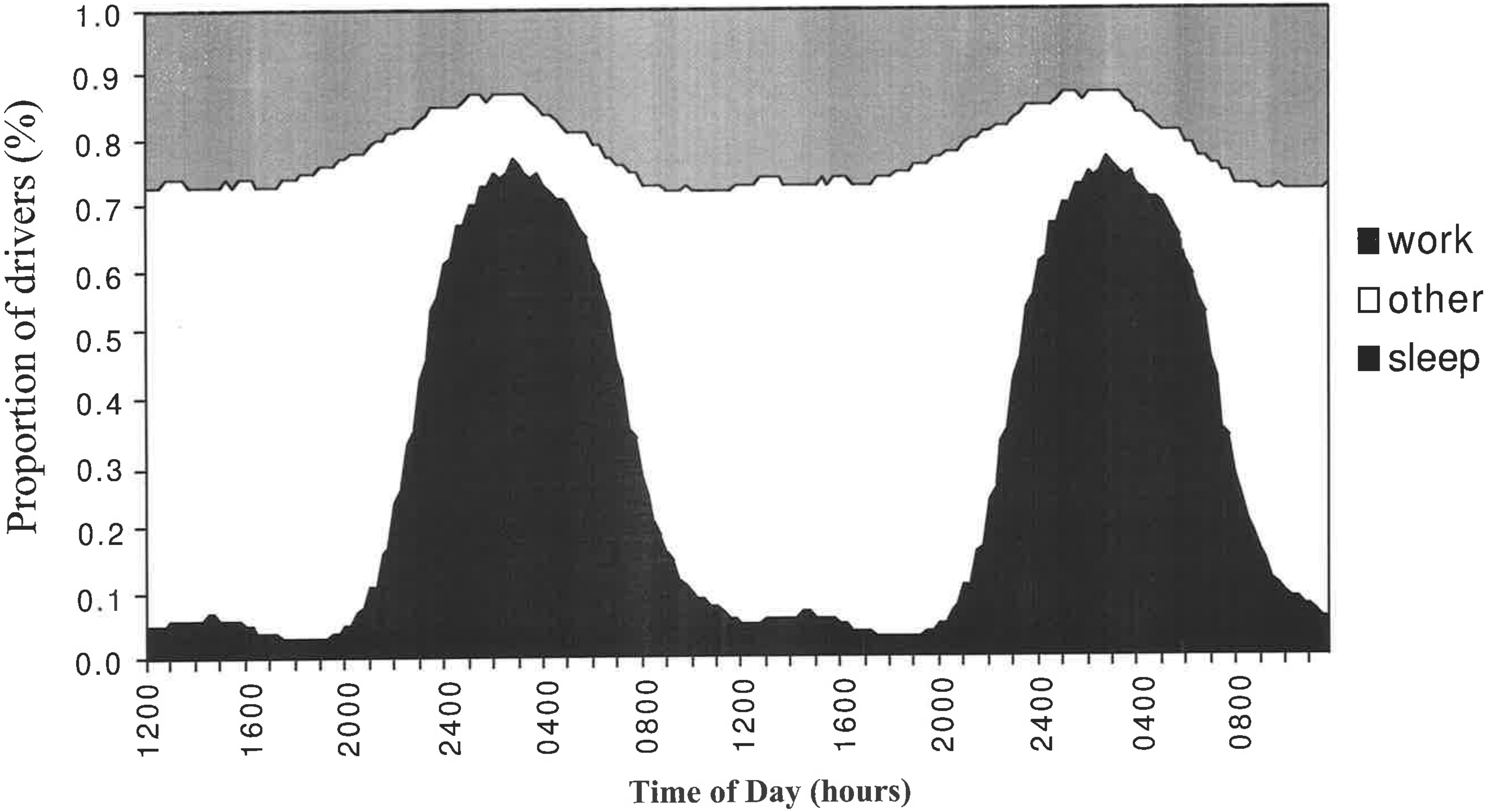


Figure 2. Double plot of the average proportion (%) of all train drivers for sleeping (black area), working (grey area) or engaged in other activities (white area) for at hourly intervals across the 24-hour day.

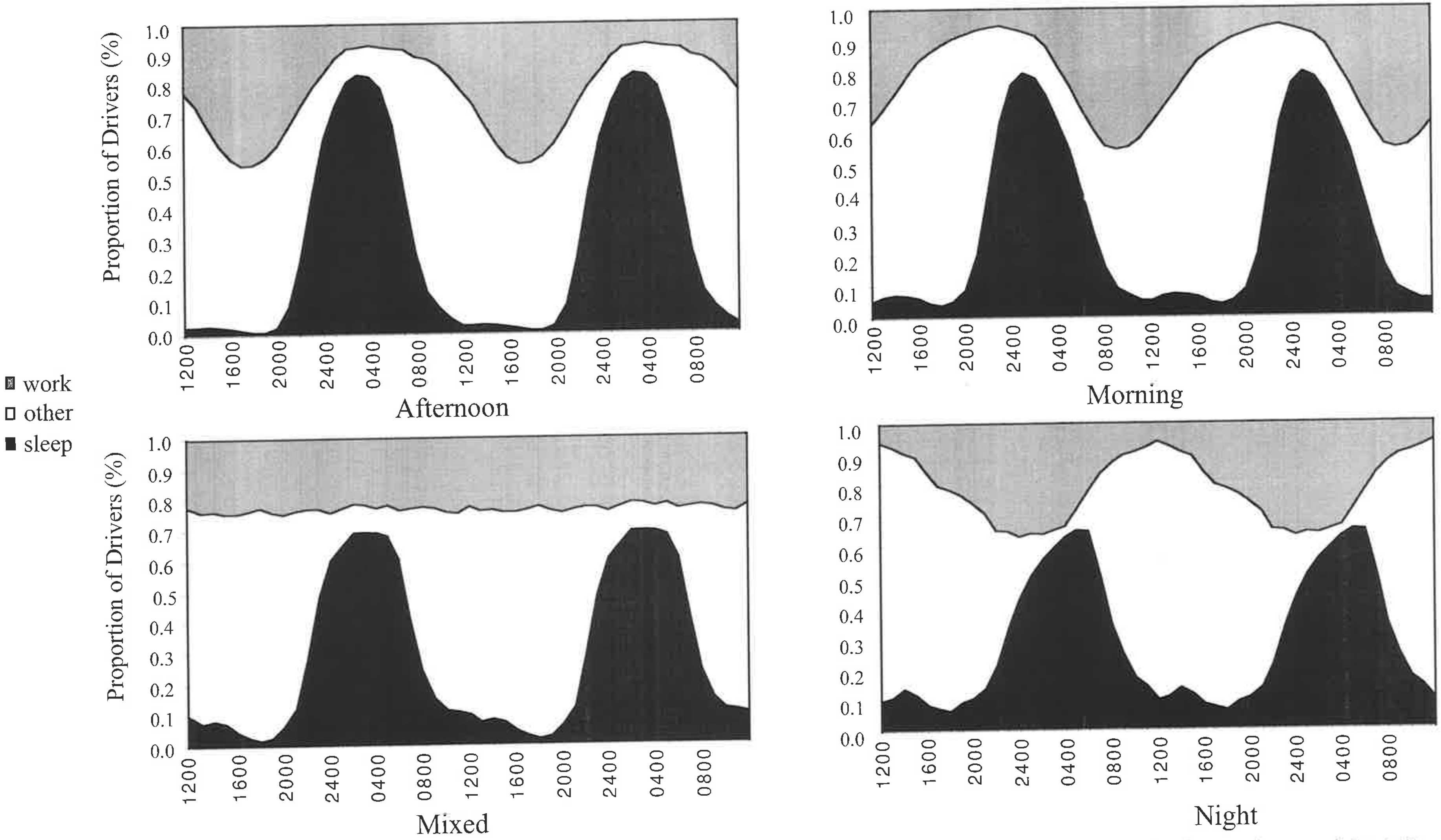


Figure 3. Double plot of the average proportion (%) of drivers working either predominantly afternoon, mixed, morning, or night shifts, sleeping (black), working (grey), or engaged in other activities (white) for hourly intervals across the 24-hour day.

Table 2. Repeated measures ANOVA results for the timing of sleep on days on and days off, for all drivers and for shifts that are predominantly either morning, afternoon, night and mixed.

	Main				Interaction	
	day on/day off		time-of-day		day on/day off x time-of-day	
	F(df)	p	F(df)	p	F(df)	p
Combine	240 (1, 2213)	*	1841(23, 23)	*	76 (23, 50899)	*
Morning	125 (1, 616)	*	684 (23, 23)	*	89 (23, 14168)	*
Afternoon	18 (1, 595)	*	913 (23, 23)	*	3.8 (23, 13685)	*
Night	17 (1, 150)	*	46 (23, 23)	*	18 (23, 3450)	*
Mixed	95 (1, 846)	*	651 (23, 23)	*	29 (23, 19458)	*

* = p <0.0001

Day on/Day off

Combined

Repeated measures ANOVA revealed that there was a significant main effect for days on/days off, and for time-of-day. Figure 4 shows that for both days on and days off work there was significantly less sleep during the day-time compared to the night-time. In addition, there was a significant interaction effect between time-of-day and days on/days off (see Table 2). Between 2300-0600 hours approximately 20-25% less drivers are sleeping on a day on compared to a day off. On average drivers slept significantly more (1.3 hours) while on a day off work compared to a day on (see Table 1).

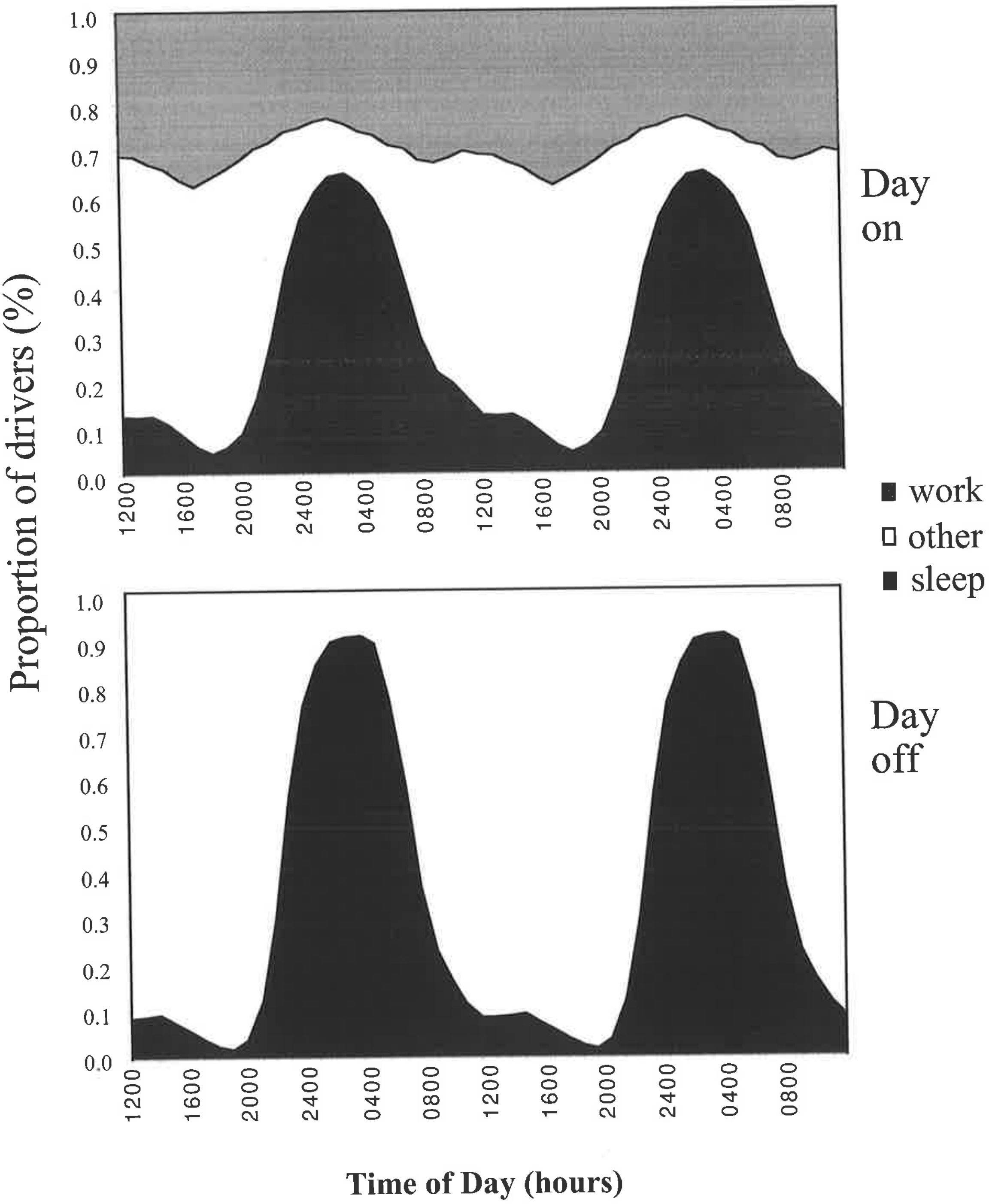


Figure 4. Double plot of the average proportion (%) of train drivers sleeping (black area) , working (grey area) or engaged in other activities (white area) on days on (top plot) and days off (bottom plot) at hourly intervals across the 24-hour day.

Shift Type Day on / Day off

Figure 5 depicts the proportion of an average day on and an average day off spent sleeping for drivers working shift schedules that are either predominantly afternoon, morning, mixed or night.

Average amount of sleep per day (± s.e.m.) and the number of drivers in each shift type can be seen in Table 1.

For each shift type repeated measures ANOVA revealed a significant main effect for day on/day off, and time-of-day, and a significant interaction effect between day on/day off and time-of-day. Results of this analysis can be seen in Table 2.

Afternoon Shift

On average, drivers on predominantly afternoon work schedules slept 0.6 hours less on days on compared to days off (see Table 1). In addition, although there was a significant difference in the timing of sleep it was relatively small (see Figure 5). Drivers in both groups slept proportionally more between 2200-0900 hours, than between 1000-2100 hours.

Morning Shift

On average drivers on predominantly morning work schedules slept more between 1900-2300 hours and less between 0000 and 1000 hours on days on compared to days off (Figure 5). In addition, drivers slept 1.6 hours less per day on average on days on compared to days off (see Table 1).

Mixed Shift

On average drivers on predominantly mixed work schedules slept 1.3 hours less on days on compared to days off (see Table 1). In addition on days on drivers slept proportionally less between 0000-0800 than for the same time on days off and the timing of sleep was relatively similar on days on and off, although they were statistically different (see Figure 5 and Table 2).

Night Shift

On average drivers on predominantly night work schedules slept more between 0800-1800 on days on than on days off (Figure 5). In addition, during days on they slept 1.6 hours less than for days off (see Table 1).

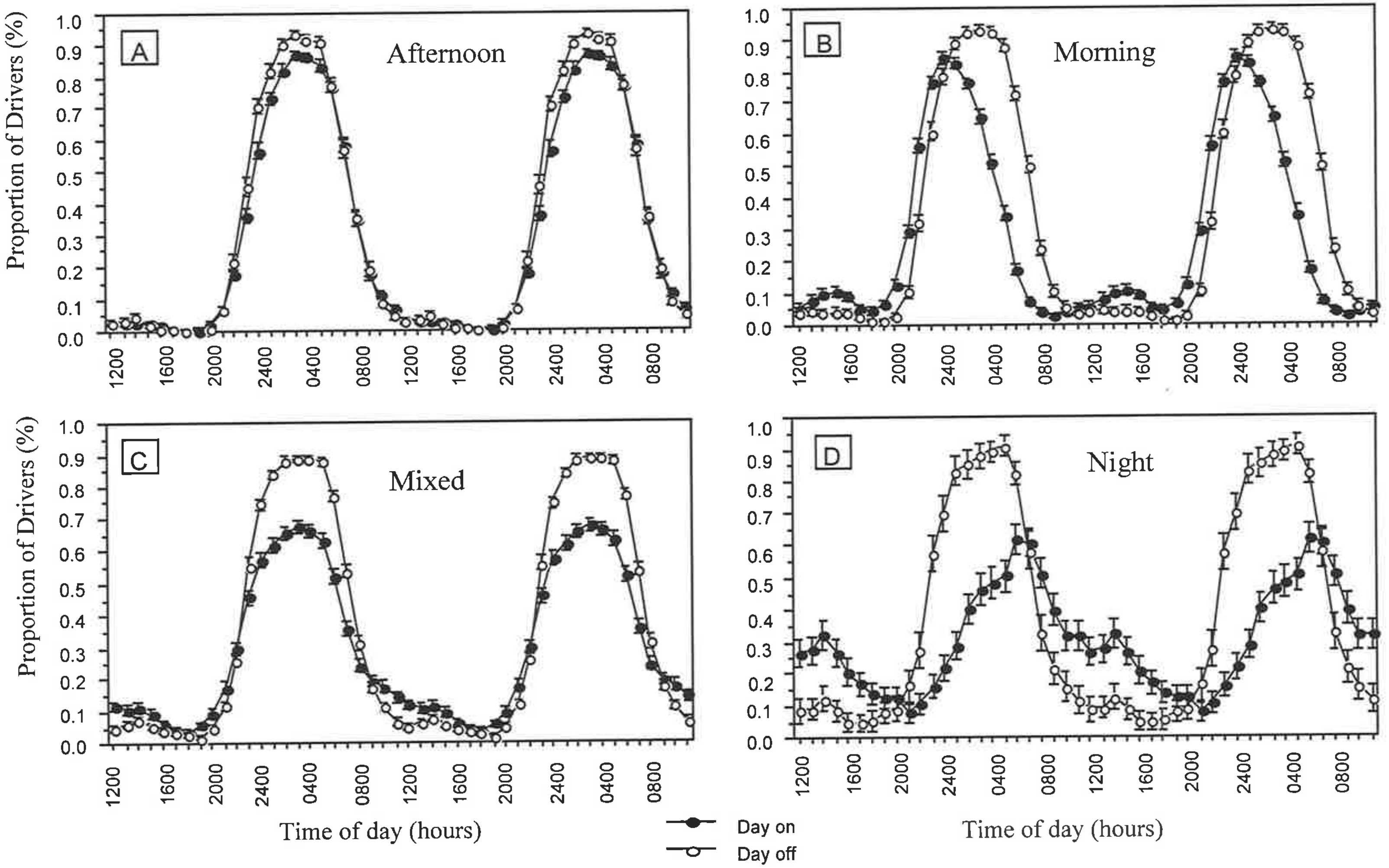


Figure 5. Double plot of the average proportion (%) of train drivers sleeping on days on (closed circles) and days off (open circles), for predominantly afternoon (a), morning (b), mixed (c) and night (d) shifts at hourly intervals across the 24-hour day.

Individual and Demographic Factors

Table 3 shows the factors, number of drivers in each factor, and average amount of sleep per average day for each factor (± s.e.m.).

Living with Partner

On average there was no difference in the amount of sleep that drivers living with and without a partner received. There was a significant interaction between the time of day and living with or without a partner (F(23, 5106)=3.817, p<0.0001). This can be seen as a difference in the timing of sleep for both groups.

Looking at Figure 6 (a), it can be seen that drivers with partners get more sleep between 2300 and 0500 hours than drivers without partners, but that they get less sleep than drivers without partners do during the hours 0800 to 1800 hours.

Age

On average there was no significant difference in the amount of sleep between the two age groups. However, there was a significant interaction between the time of day and age (F(23, 5152)=2.5, p<0.0001). This can be seen as a difference in the timing of sleep for the two age groups.

Looking at Figure 6 (b), drivers aged 40 years or above had more sleep between 2000 and 0300 hours than drivers below 40, however, they have less sleep than drivers below 40 between 0500 to 1100 hours. Therefore, it appears that drivers 40 and over get more sleep in the evening and early morning, and drivers under 40 get more sleep in the mid morning.

Morning-Eveningness

On average there was no significant difference in the amount of sleep that morning-and intermediate type drivers had. However, there was a significant interaction between the time of day and Morningness-eveningness (F(23, 4738)=5.35, p<0.0001). This can be seen as a difference in the timing of sleep for both groups.

Looking at Figure 6 (c), morningness-type drivers had more sleep between 1900 and midnight than intermediate-type drivers did, but they had less sleep than intermediate-type drivers between 0200 to 1100 hours did. This suggests that morningness-type drivers get more sleep in the evening and intermediate-type drivers get more sleep during the morning.

Young Children

On average there was no significant difference in the amount of sleep or in the timing of sleep that drivers living in a household with and without young children received. Figure 6 (d), shows sleep across the 24 hour day for those with young children and for those without.

Table 3. The number of drivers and amount of sleep per average day (mean ± s.e.m.) in hours for drivers either: living with or without a partner, living with young children or not, age, and morningness-eveningness.

Factor	# of	Hour of Sleep per day
Living with Partner		
Partner	184	7.1 (0.12)
No Partner	40	7.0 (0.24)
Young children (<12)		
Yes	97	7.1 (0.17)
No	127	7.1 (0.14)
Age (years)		
under 40	120	7.0 (0.14)
over 40	106	7.1 (0.14)
Morning-Evening		
Morning	20	6.9 (0.34)
Intermediate	188	7.1 (0.12)
Evening	0	NA

NA = not available

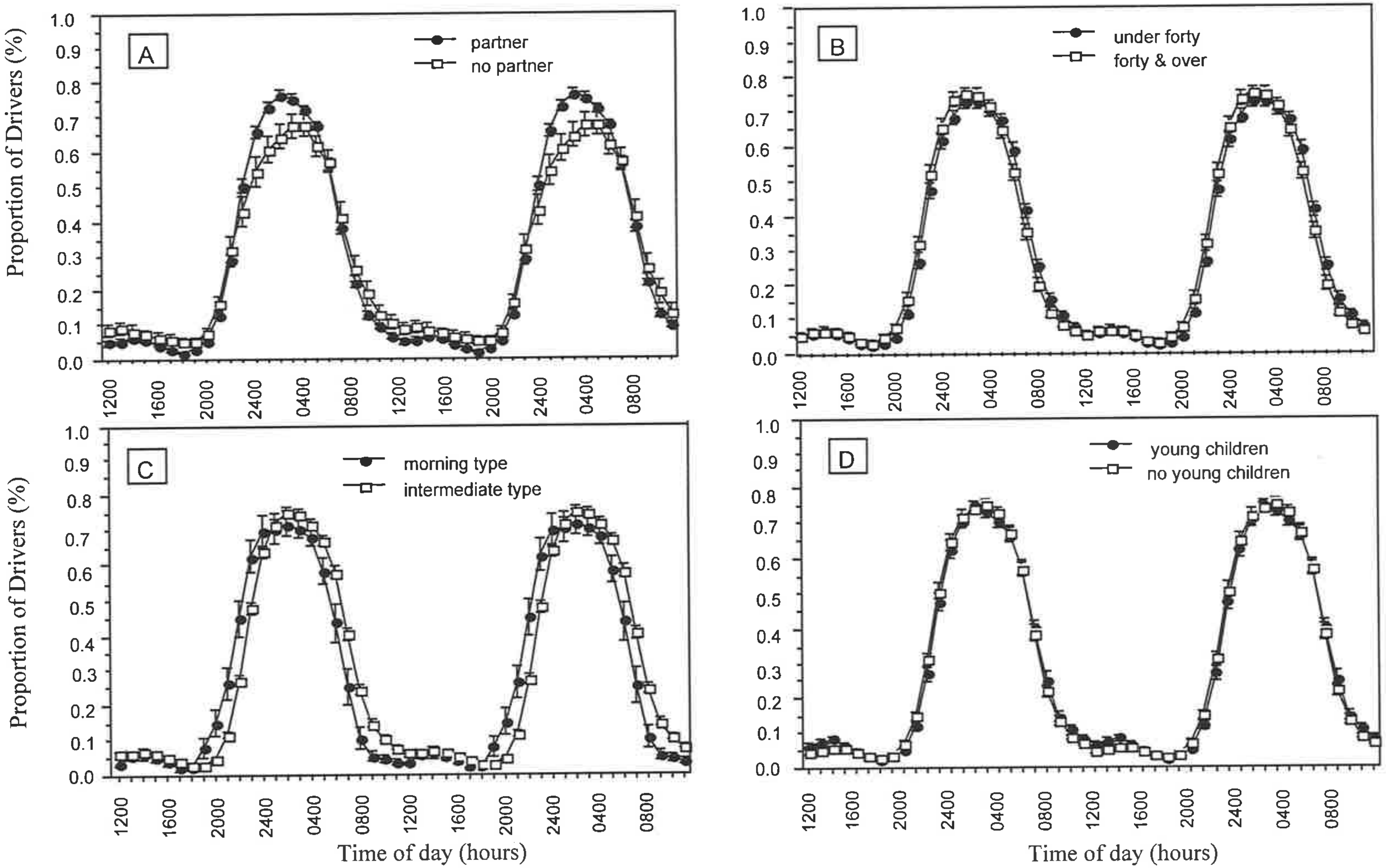


Figure 6. Double plot of the average proportion (%) of train drivers that are either living with or without a partner (a), aged below 40 and 40 and above (b), morning or intermediate types (c) and those with or without young children in the household(d), sleeping at hourly intervals across the 24-hour day.

6.5 Discussion

Overall, the results of this study indicate that the circadian rhythm in sleep-wake was strong and that sleep maintained a typical nycthemeral pattern, regardless of work schedule, suggesting that the drivers sleep/wake patterns did not adapt to the irregular work schedule. On average, drivers obtained relatively little sleep during the day compared to during the night with little influence from work schedule excluding night shifts, and individual and demographic factors.

When all sleep periods were examined drivers slept on average proportionally more during the night-time hours (2200-0800 hours) compared to the day-time hours when on an irregular shift schedule. In the Australian rail industry drivers rarely work one specific type of shift and start times are erratic. As a result of this it was necessary to group drivers into predominant shift types, in order to determine the influence of shifts at different times-of-day, on the timing of sleep. Drivers were allocated to either afternoon, morning, night or mixed shifts, and analysis indicated that there was little difference between the pattern of sleep for these groups. That is, although, the work times across the day were significantly different between shift types (see figure 3) the probability that a driver was sleeping was greater during the night-time compared to during the day for each shift type. For example, even when drivers worked a predominantly mixed shift schedule and work was relatively evenly distributed across the 24-hour day during the two-week study period, sleep maintained its position within the typical circadian cycle of sleep-wake.

When sleep periods were separated into days on or off a similar pattern of sleep was observed, such that, drivers slept proportionally more at night than during the day-time. Heitmann and co-workers (1997) reported a similar finding for train drivers on irregular shift schedules in North America. In the current study, drivers on a day off slept more between 2400 and 0800 hours than for a day on, but on both days on and off drivers slept proportionally less during the day than at night. There was also a difference in the amount of sleep obtained on days on and off. On average there was 1.2 hours less sleep during a day on compared to a day off. Foret and Lantin (1972) reported that railway personnel in Europe on irregular schedules also slept by 1-2 hours less on days on compared to days off.

In addition, when drivers were categorised into predominant shift types for a day on and a day off a similar pattern to that for the combined results was observed (see figure 4). There were significant differences in the timing of sleep between both days on and off for all shift types. Specifically, the drivers slept predominantly more during the night-time compared to the day-time hours regardless of whether it was a day on or off. The only exception was for those drivers who worked predominantly night work. As expected during a day on these drivers slept proportionally more during the day than for the drivers in the other shift types. In addition, for all predominant shift types drivers slept proportionally less (approximately 1 hour) on a day on compared to a day off work (see table 1).

In the current study, sleep was reported as an amount of sleep on an average day, which included main sleep periods and naps. The results indicate that, on average, drivers did not have less than 6.6 hours of sleep (predominantly morning type schedule, day on). The greatest amount of sleep per day on average was 8.9 hours on a day off for the predominantly night shiftworkers. The increased sleep for this group could be a result of drivers attempting to catch-up on sleep on their days off (Knauth *et al.*, 1980). Overall, on an average day, drivers had approximately 7.6 hours of sleep. Therefore, on average, the drivers in this study were able to obtain a "reasonable" amount of sleep over an average 24-hour period. This may not have always been obtained in a single sleep period. In the future it would be useful to examine the relationship between amount of sleep and the number of consecutive days worked and days off, however, this is not within the scope of the current thesis.

While work schedule had some influence on the timing and amount of sleep for this group of drivers we also examined the influence of both individual and demographic factors. On average, age, morning-eveningness type, and domestic situation had no significant effect on the amount of sleep that drivers obtained, however, age, partner in the household, and morning-evening type did have a significant effect on the timing of sleep .

Research has suggested that for shiftworkers sleep disturbance begins to increase after the age of 40 years (Foret *et al.*, 1981; Akerstedt and Torsvall, 1981; Parkes *et al.*, 1994). Van Good *et al.*, (1986) and Czeisler *et al.* (1992) report that older individuals have an earlier circadian phase, which has been associated with a reduction in the ability to adapt to changes in circadian rhythms and with reductions in sleep (Breithaupt *et al.*, 1978). It may, therefore, be expected that younger drivers would have significantly altered their sleeping patterns to match their work schedule compared to the older drivers. However, while in the current study, drivers older than 40 years of age slept proportionally more earlier in the evening between 2000-0300 hours than those under 40, there was no difference in the amount of sleep on an average day and drivers in both age groups maintained a typical nychthermal sleep-wake pattern. It may be that if drivers were in their sixties more of a difference would be observed, due to the significant changes in sleep in this age group normally, but there were no drivers in this age group in the current study.

Morning-types have been reported to be less able to cope with shiftwork schedules than are evening-types (Hilderbrandt *et al.*, 1979; Torsvall *et al.*, 1980) as they have a circadian phase position similar to that seen in older individuals (Van Good *et al.*, 1986; Czeisler *et al.* 1992). In this study morning-type drivers slept more between 1900 hours and midnight, while intermediate types slept more between 0200 and 1100 hours. However, there was no significant difference in the amount of sleep for drivers who were either morning or intermediate types. When you look at figure 6 you can see that as has been previously reported drivers over 40 years of age are more morning types in the timing of their sleep.

It is interesting to note that the majority of drivers scored themselves as intermediate types with a small proportion of morning types, while no drivers scored themselves as an evening type. This may be a normal sampling phenomenon as reported by Ashkenazi *et al.* (1997) that in a group of randomly studied subjects only 5-10% are true morning or evening-types. Alternatively there may be a self-selection factor for shiftwork / train driving. It may be that individuals that are either evening or morning types do not chose to work this type of schedule. The years of shiftwork experience in this group of drivers ranged from 3-41 years. Therefore, it may be reasonable to assume that most individuals would have already decided after 3 years whether they could cope with this type of shift schedules. Harrington (1978), suggests that 20-30% of shiftworkers leave within the first 2-3 years due to important health problems.

It has frequently been suggested that domestic factors, for example living with a partner and children, would have a significant effect on the amount of sleep or a more profound effect on the timing of sleep. There was, however, no significant difference in the timing or amount of sleep as a result of living with or without young children in the house. There were, however, changes to the timing of sleep for drivers living with a partner, but again no difference in the amount of sleep obtained. This may be because anecdotally in the group of drivers studied most individuals with children had a partner. In addition, many drivers commented that one of the adverse effects of their shift schedules was that they missed time with their children, and their partner played the major care giving role. In many instances drivers anecdotally noted that "the job came first" and the "family fitted around the work schedule".

Although, the timing of sleep was statistically different for age, partner in the household, and morning-evening type in each case, the timing of the sleep period was displaced on average by only 1-2 hours, and all drivers slept proportionally more during the night-time compared to the day-time. Further analysis is required to determine whether drivers over a sequence of shifts functionally alter their sleep patterns to match their work schedule, as currently only average results are presented.

Overall, the findings of the current study indicate that the influence of the circadian rhythm of sleep-wake is strong and that driver sleep patterns were not adapting to their work schedule. That is, on average, drivers spent proportionally less time sleeping during the day compared to during the night-time hours. Despite the statistical significance of the difference in the timing of sleep for most groups (excluding days on for night workers), the magnitude of the change within groups is small. The circadian rhythm of sleep-wake appears to have the strongest influence on the sleep patterns of this group of irregular shiftworkers, while individual and demographic factors play only a minimal part in influencing when these drivers sleep.

Furthermore, because these drivers are sleeping proportionally less during the day compared to the night-time hours there may be significant implications for the amount of sleep that can be accumulated for breaks that occur during the day-time. In view of these findings, measures should be taken to ensure that irregular work schedules allow to drivers adequate time off between subsequent shifts, particularly when recovery is based on day-time sleep.

Chapter Seven

The effect of break onset time on the amount of sleep accumulated by irregular shiftworkers during breaks between shifts.

7.1 Introduction

In recent decades the occupational health and safety risks associated with shiftwork in general and night work in particular have been well established. These risks are of great concern in many industries (Mitler *et al.*, 1988; Akerstedt, 1995a and b; Leger 1994). The increased risk of accident and reduced productivity and efficiency associated with shiftwork are a result of reductions in sleep quality and duration and the necessity to be working at a time when the ability to perform at peak is poor (Mitler *et al.*, 1988).

In addition to the physiological (e.g. circadian rhythms) (Lavie, 1986; Czeisler *et al.*, 1980), environmental (e.g. light, noise) and social factors (domestic responsibilities) (Walker, 1985; Tepas *et al.*, 1993; Knauth *et al.*, 1975) that influence sleep, the opportunity for shiftworkers to sleep is limited by the duration of scheduled breaks. Kurumatani *et al.* (1994) reports that break durations of 16 hours are optimal, as it is assumed that this would enable a worker to obtain approximately 7-8 hours sleep. However, in many shiftwork industries (e.g. Australian rail industry), the minimum break requirements between consecutive shifts are as little as 8-11 hours. Kurumatani and colleagues (1994) report that such a quick rotation between shifts, results in less sleep than longer breaks, and that break durations as short as 6 hours result in sleep durations of only 3 hours.

The duration of sleep between consecutive shifts is also influenced by circadian factors. For example, shiftworkers sleep proportionally less during the day than at night due to the strong circadian rhythm in sleep propensity (Lavie, 1986; Czeisler *et al.*, 1980; Kogi *et al.*, 1985; Reid *et al.*, 1997; Chapter 6). This means that the amount of sleep accumulated for breaks during the day may be lower than for a break of similar duration during the night. Sleep duration has been shown to be a function of sleep onset time.

Specifically, sleep that begins during the day-time is typically shorter than sleep that begins at night (Kogi *et al.*, 1985; Knauth and Rutenfranz, 1981).

Rather than recording sleep onset times of employees for different shifts it may be more practical to determine sleep as a function of break onset times. This may allow industries to estimate the sleep patterns of their employees aiding them with the scheduling of shifts to enable employees an adequate opportunity to sleep between shifts.

Due to the serious performance impairment that may be associated with sleep loss, the current study aims to determine when train drivers on irregular shift schedules slept in relation to break onset. Secondly, it aims to determine how much sleep they accumulated during break periods of various lengths as a function of break onset time.

7.2 Method

Subjects

Two hundred and fifty three train drivers with a mean (± s.d.) age 39.7 (± 6.8) gave informed consent to participate in this study for two consecutive weeks. During the study drivers completed daily sleep and work diaries.

Procedure

In order to select representative working conditions from throughout the rail industry 14 depots were chosen following consultation with the rail industry and unions. Both passenger (suburban and country including interstate), and freight driving (short and long haul) were represented.

The length of shifts varied across depots, but were typically between 6-12 hours. The range of shifts recorded was between 2-30 hours in duration. Due to different scheduling methods across and within organisations drivers were given from between 12 hours to 2 weeks notice of their next shift. In addition, alterations to work schedules at short notice was a common occurrence, with as little as 2-4 hours notice of changes.

Shiftwork within the Australian rail industry was classified as irregular (see Figure 1a and b in Chapter Six). This figure depicts a two week work and sleep schedule for a driver from (a) a passenger and (b) a freight depot.

Sleep/Wake Diary

Train drivers completed a sleep diary daily, recording all sleep periods including awakenings. Diaries were filled in directly upon waking, to ensure more accurate recall of sleep. In addition, subjects were asked to rate the quality of their sleep on a scale from 1-5. A score of one was rated “a good sleep” and a score of five “a poor sleep”, subjects also rated how sleepy or awake they felt before going to sleep and when they woke up using the 7 point Stanford Sleepiness Scale (SSS).

Work diary

Drivers recorded the start and finish time of each shift in a work diary. Drivers also identified the type of work that each shift involved, which was typically recorded as a code unique to each depot. If drivers had a day off this was recorded rather than leaving the day blank, as some shifts carried over into the next day.

7.3 Analysis of Results

Information from the sleep and work diaries was used to produce graphs representing sleep probability profiles (Figure 2) and patterns of sleep accumulation (Figure 3).

The sleep probability graphs represent the probability that a driver was sleeping at any point during the 48 hours following break onset. Twenty-four curves were produced, representing the sleep probability profiles for break onsets occurring in each 1-hour period across the 24-hour day. These curves are presented in Figure 2. The figure is best conceptualised as a topographic map, with each colour representing a different level of sleep probability. Consider the probability that a driver was sleeping at 0400 hours following a break beginning at 1800 hours as an example. The graph is red at the intersection of these values, corresponding to a sleep probability value of 0.8-0.9. This indicates that if a driver began a break at 1800 hours, there was an 80 to 90% probability that he was sleeping at 0400 hours.

In the second stage of data analysis, information from the sleep and work diaries was used to produce a graph that indicates the pattern of sleep accumulation in time off work depending on the time of day that the break began. Figure 3 shows the sleep accumulated in breaks between work periods that begin at different times across the 24-hour day. Consider the example of an 11-hour break that begins at midnight. The graph is orange at the intersection of these values, corresponding to a value of 6-7 hours of accumulated sleep. This indicates that a driver will accumulate 6-7 hours of sleep in an 11-hour break beginning at midnight. However, if an 11-hour break begins at midday, then these values intersect in the blue section of the graph. This indicates that a driver will accumulate only 2-3 hours of sleep in this break.

7.4 Results

Referring to Figure 2, it can be seen that for breaks beginning between midday and 0400 hours, most sleep occurred during the night (2200 to 0700 hours) and little sleep occurred during the day (1000 to 2000 hours). This is shown by the fact that the coloured section of the graph (higher sleep probability) occurs during the night, whilst the grey section of the graph (lower sleep probability) occurs during the day. Despite this general trend, the graph also indicates that as break onset becomes later over this period (midday to 0400 hours), drivers slept later in the morning. For example, for breaks beginning at 1300 hours, sleep probability dropped to 0-0.1 by 0800 hours; for breaks beginning at 1900 hours, sleep probability dropped to 0-0.1 by 0900 hours; and for breaks beginning at 0100 hours, sleep probability dropped to 0-0.1 by 1100 hours.

For breaks beginning between 0400 hours and midday, the majority of sleep also occurred during the night. However, more sleep occurred during the day for these breaks, than for breaks beginning between midday and 0400 hours. For example, sleep probability was 0-0.1 at midday for breaks beginning between midday and 0400 hours. In contrast, sleep probability at midday for breaks beginning at 0800 hours was 0.5-0.6.

Referring to Figure 3, it can be seen that there were differences in the rate of sleep accumulation between breaks beginning at night and those beginning during the day. For example, 6-7 hours of sleep was accumulated in an 11-hour break beginning at midnight (orange section), but only 1-2 hours of sleep was accumulated in an 11-hour break beginning at midday (violet section). Similarly, it took less than 8 hours to accumulate 6 hours of sleep in a break beginning at midnight, but 17 hours to accumulate the same amount of sleep in a break beginning at midday.

Sleep as a function of Break-onset

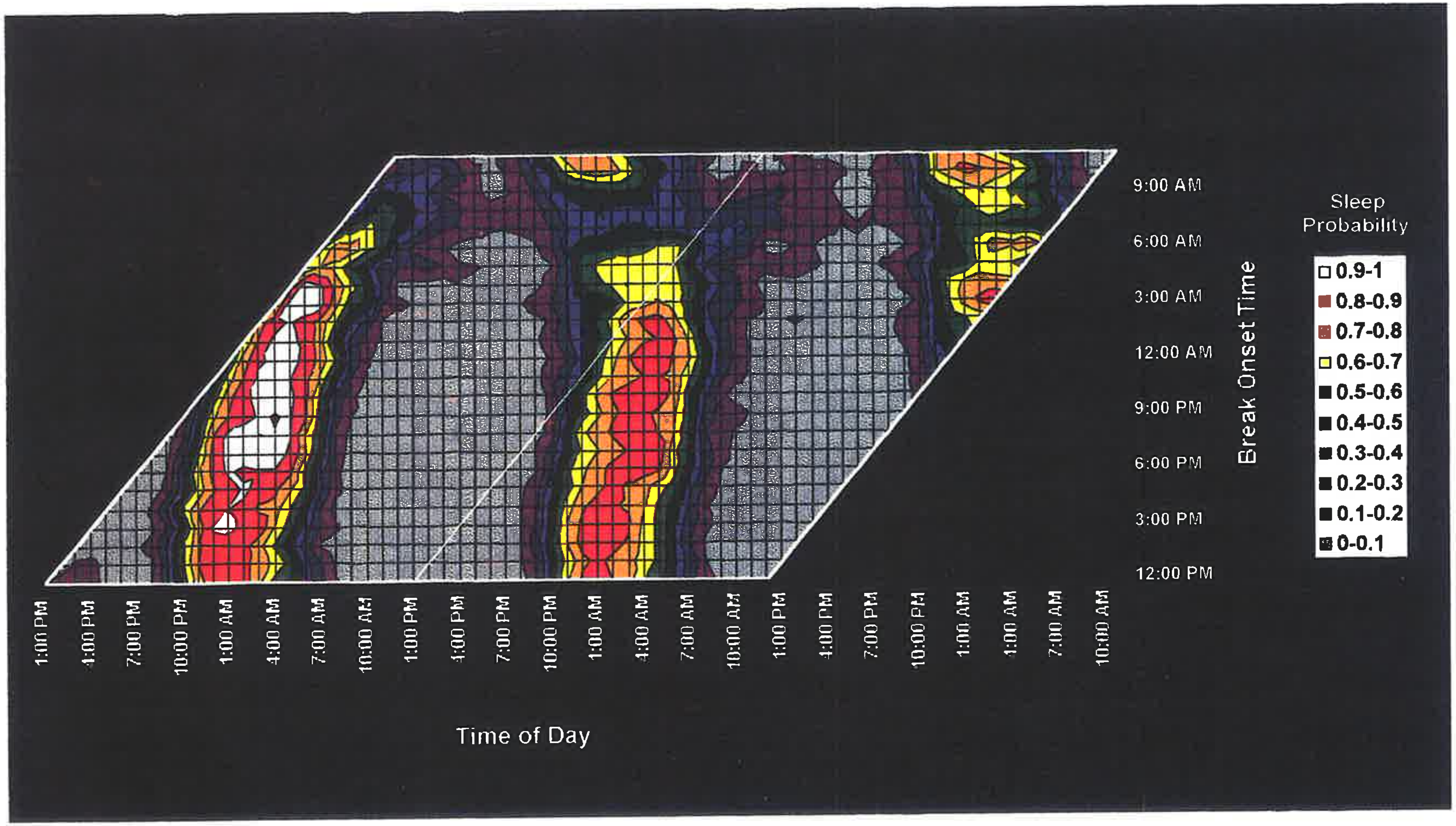


Figure 1. Graphic representation of the average sleep probability across the 24-hour day as a function of break onset time (hours). The colours in the legend indicate the probability that a driver will be sleeping (from 0-1).

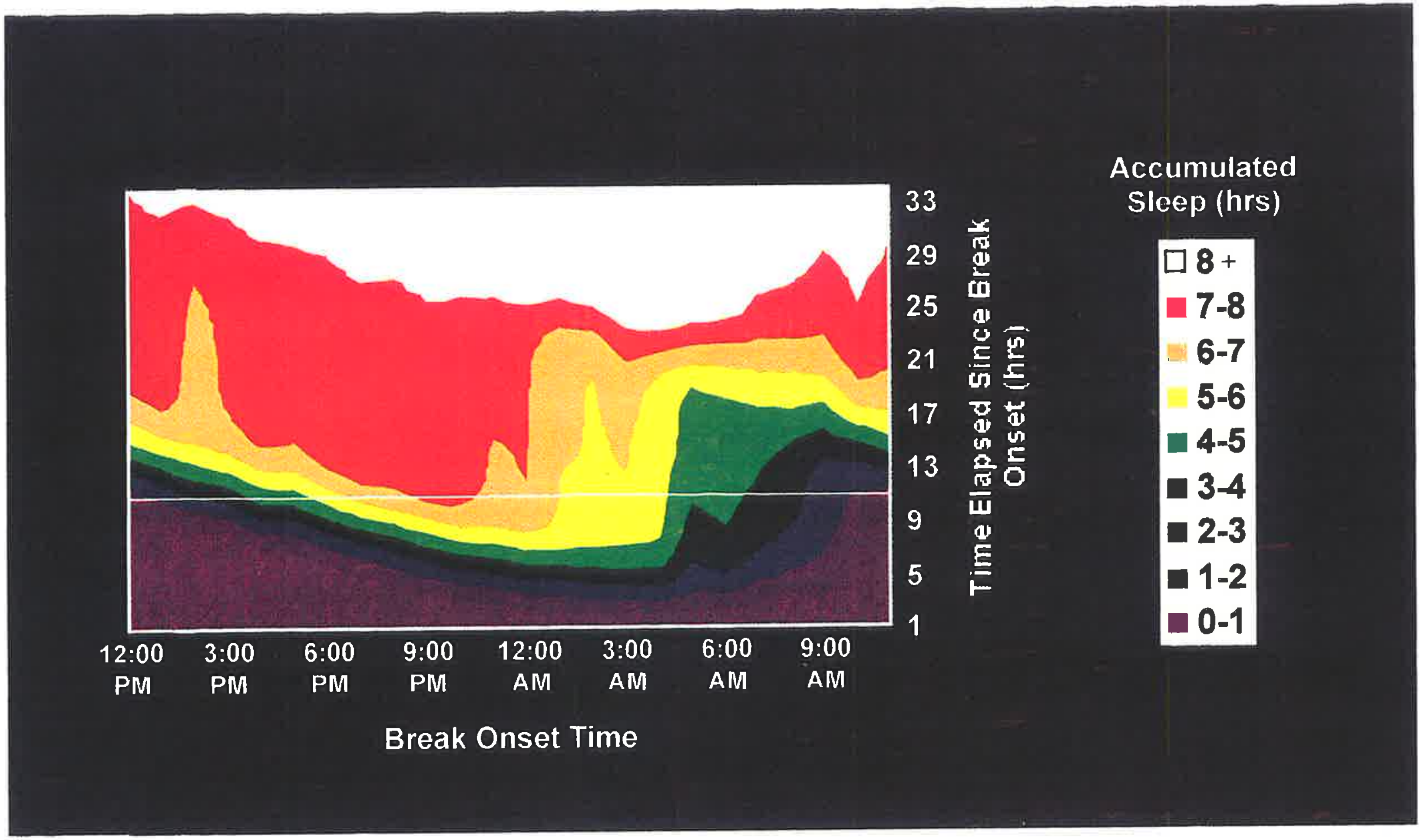


Figure 2. Nomograph of the sleep accumulated as a function of break duration. Colours indicate amount of sleep accumulated from 0-8+ hours.

7.5 Discussion

The current study indicates that time of break onset had a negligible influence on sleep probability (see figure 1). As a result, the pattern of sleep accumulation (see Figure 2) was markedly influenced by time of break onset. Regardless of the time-of-day that a break began, the majority of sleep for that break was obtained during the night. Thus, the accumulation of sleep depended on the amount of time it took to reach a point of high sleep probability (i.e. night-time). For breaks that began before this period in the sleep cycle, sleep was accumulated quickly as there was only a short period of time that had to elapse before a period of high sleep probability was reached. In contrast, for breaks that began after this period in the sleep cycle, sleep was accumulated slowly as a greater period of time had to elapse before a period of high sleep probability was reached.

It was determined that drivers maintained a fairly typical nocturnal sleep pattern, particularly for breaks that began between 1200-0300 hours. For breaks between 0300-1100 hours there was some sleep during the day-time hours 0900-1800 hours, however, during this time sleep probability was low, between 0.1-0.3 (see Figure 1). There also appeared to be napping particularly when breaks began during the early afternoon. Some drivers appeared to nap early in the break, followed by a period of high sleep probability later in the day. For example, when drivers had a break that commenced at 1200 hours there was a period of increased sleep probability between 1300-1600 hours, then at 1600 hours the probability of sleep declined again until 2000 hours.

The propensity to initiate and maintain sleep (i.e. sleep duration) follows a distinct circadian rhythm. For example, Lavie (1986) reported that it was easier to initiate sleep between 2000 and 0600 hours and again to a lesser degree between 1300-1500 hours than at other times of day. Other researchers report that the length of sleep depends on the time of sleep onset, and where in the circadian phase sleep is initiated (Czeisler *et al.*, 1980; Kogi 1985). It is not surprising, therefore, that the drivers in the current study postponed sleep to times of high sleep propensity. For example, for breaks that begin at 2400, the probability that a driver is sleeping at that time is high. In contrast, for breaks that begin at 1400 hours, sleep is postponed for approximately 6-8 hours until they reach a time of higher sleep probability at approximately 2000-2200 hours.

As a result of low sleep probability for breaks commencing during the day-time, there will be an impact on the amount of sleep that drivers accumulate between shifts. The sleep probability curves from figure two were used to calculate how long it would take to accumulate between 0-1 and 8+ hours of sleep depending on when the break commenced. Figure 2 reveals that the time elapsed since break onset required to accumulate different amounts of sleep varied in a circadian fashion. That is, for breaks beginning between approximately 0400-1100 hours it took considerably longer, about 23-24 hours to accumulate 7-8 hours sleep. In contrast, for breaks that began between 1200-0400 hours it took approximately 15 hours. It may have taken approximately one day to accumulate 7-8 hours sleep, because the average amount of sleep per day was 7.6 hours.

In the current study we examined the amount of sleep accumulated in a break of a specific duration and starting time. In comparison, Kurumatani *et al.* (1994) investigated the relationship between break onset and sleep duration. They reported that there was a high correlation (r=0.95) between sleep duration and the duration of the break between consecutive shifts, they also concluded that a 16 hour break was required to get 7-8 hours of sleep. This is in contrast to the between 15-24 hours required, depending on the time of break onset, to accumulate 7-8 hours of sleep in the current study. However, they did suggest that “change overs” that have breaks that occur during the day will result in shorter sleep durations than breaks at other times. Similarly Akerstedt *et al.*, (1991) reported that sleep after a night shift is typically not longer than 5-6 hours and may be reduced further when followed by an evening shift. In comparison, the results of the current study suggest that following a night shift (i.e. a shift with a break commencing between 0400-1100 hours) a break duration between 16-21 hours is required to get 5-6 hours of sleep. Therefore, if the break duration was reduced, due to an evening shift the following night, sleep would be further curtailed possibly to as low as 3-4 hours. Furthermore similar findings are reported by Totterdell and Folkard (1990) and Knauth *et al.* (1983) who showed that for breaks between consecutive shifts of nine hours sleep duration was reduced to an average of only three hours.

Kurumatani *et al.* (1994) also suggests that sleep durations were reduced due to both circadian factors and other social and domestic activities. Similarly, Kecklund and Akerstedt (1995), suggest that shiftworkers may give a higher priority to social activities than to sleep and may therefore interrupt day sleep earlier to participate in these activities. Previous analysis in this thesis suggests that the major contributing factor influencing the pattern of sleep is circadian factors. For example, analysis showed that factors such as age, domestic status and morning-eveningness type had minimal influence on the timing of sleep in this group of irregular shiftworkers (see chapter 6).

Considering the evidence to suggest that sleep is reduced during day-time sleep periods it is surprising that there are few if any organisations that consider time-of-day when scheduling minimum break requirements. In many cases within the Australian rail industry drivers are working several consecutive shifts with rostered breaks as short as

8-12 hours between shifts. The results of the current study suggests that following shifts with break durations of 8-12 hours, that drivers are rarely able to accumulate 7-8 hours sleep, and are usually obtaining 4-5 hours of sleep. Sleep as short as 4-5 hours/day may have serious implications for driver performance. As several studies of sleep restriction and sleep disruption report sleep durations as short as 4-5 hours may result in serious decrements in performance (see Gillberg (1995) for a review; Dinges *et al.*, 1997). In addition, drivers whose schedule require a series of several consecutive shifts may be accumulating a considerable sleep debt, due to the reductions in sleep accumulated during the day-time (Tilley *et al.*, 1981; Javanis and Kaneko, 1990). When reductions in performance due to sleep debt and working at night are combined, drivers are likely to experience significant increases in sleepiness and reductions in alertness and performance. Specifically, there may be significant reduction in worker performance and efficiency that may result in an increased risk of accidents (Mitler *et al.*, 1988; Leger, 1994).

Taken together the results of the current study suggest that break onset time and break duration are important factors in determining the amount of sleep that drivers accumulate. Therefore, time-of-day rather than simply break duration should be considered when scheduling breaks to allow adequate recovery time.

Discussion and Conclusions

8.1 Overview

Chapter one introduced shiftwork and its influence on circadian rhythms. It showed that disruption in circadian rhythms due to shiftwork lead to reductions in sleep, alertness and performance and increases in sleepiness particularly for night and early morning shiftworkers.

Chapter two quantified the effects of sustained wakefulness on performance in a way that could be readily understood to provide people with a more "easily grasped index" of the impact of sustained wakefulness on performance. This was achieved by equating the performance impairment associated with fatigue following 10-16 hours of wakefulness between 1700-0900 hours with the performance impairment associated with alcohol intoxication between 0800-1600 hours.

Chapters three, four and five covered an experimental study in which techniques for measuring sleep and performance were evaluated. These studies also examined the influence of shiftwork on sleep and performance in both younger and older subjects. In the past, most studies have not specifically compared the influence of sleep disruption on performance in younger and older subjects. Rather they have typically used young healthy volunteers or experienced shiftworkers and evaluated sleep and performance separately.

Chapters six and seven were a study of the sleep of train drivers on an irregular shift schedules. During this study the sleep/wake pattern of drivers was determined while in their normal environment using sleep and work diary techniques.

8.2 Experimental Section One

8.2.1 Chapter Two

Fatigue, alcohol and performance impairment

The aim of the study reported in chapter two was to quantitatively equate the performance impairment resulting from fatigue due to sustained wakefulness between 10-26 hours at 1700-0900 hours and alcohol intoxication condition between 0800-1600 hours. In one condition, subjects were kept awake for 28 hours from 0800 until 1200 hours the following day. In the other condition, subjects consumed 10g of alcohol at 30-minute intervals from 0800 hours until their mean blood alcohol concentration reached 0.10% or until 1600 hours. In both of these sessions cognitive psychomotor performance was measured using a short (3 x 1 minute) unpredictable tracking task at half hourly intervals from the start of the sessions.

It was concluded that performance decreased significantly in both the alcohol and sustained wakefulness conditions. In the alcohol condition performance decreased in a linear fashion. There was a slight increase in performance at low alcohol concentrations up until approximately 0.03%, and from this point on performance declined. The increase in performance above baseline levels, at low blood alcohol concentrations has been previously reported and is believed to be a result of alcohol acting as a stimulant at low blood alcohol levels (Wilkinson and Colquhoun, 1968). It could also be suggested that there is a circadian component that masks the level of decline in performance at this time in the alcohol condition (this is discussed in further detail on page 224).

In the sustained wakefulness condition, subjects were able to maintain performance close to baseline for approximately 13 hours, from which time performance declined, in a linear fashion until 25 hours of wakefulness. At this time, due to circadian factors, performance began to improve. Several studies have reported the performance impairment associated with sustained wakefulness for considerably longer periods (up to 84 hours) (Horne *et al.*, 1985a; Babkoff *et al.*, 1991; Fiorica *et al.*, 1968; Dinges and Kribb, 1991) and for the first 28 hours have shown results similar to those in the current study.

Although the impact of sleep loss on performance has been well demonstrated (Dinges and Kribb, 1991; Horne *et al.*, 1985a; Babkoff *et al.*, 1991; Fiorica *et al.*, 1968; Dinges *et al.*, 1997; Johnson, 1982), in industry and the community there is little understanding of the implications of this type of fatigue. This is despite the fact that many of this century's most spectacular and destructive industrial accidents have, at least in part, been fatigue related (Mitler *et al.*, 1988; Leger, 1994; Ehret, 1981). This lack of understanding may be because to date, the comparative risks associated with sustained wakefulness and fatigue have not been well quantified. In contrast, in most industrialised countries driving or operating machinery above a certain alcohol concentration (typically 0.05-0.10% blood alcohol concentration) is prohibited.

This study equated the cognitive psychomotor performance impairment associated with sustained wakefulness and alcohol intoxication. By doing this it was possible to quantify the impairment associated with sustained wakefulness and express it in a blood alcohol impairment equivalent. The performance impairment detected between 18-28 hours of sustained wakefulness at 0100-1100 hours was equivalent to the performance impairment measured at a blood alcohol concentration greater than 0.05%. By relating the performance impairment associated with sustained wakefulness as a blood alcohol equivalent we were able to provide an "easily grasped index" of the relative influence of extended wakefulness on performance at this time-of-day. In Australia driving is prohibited above 0.05% blood alcohol concentration and many industries require a 0.00% blood alcohol concentration for employees.

While providing a relative impairment level to alcohol intoxication this study is limited in the conclusions that can be drawn and then related to a real-world setting. One of the reasons for this is that it does not take into account the effects of different durations of wakefulness at different times-of- day. For example, if we had the subjects participate in a protocol that had them sleeping during the day-time and they woke on average at 1800 hours it would probably not take 24 hours of sustained wakefulness until they reach a level of performance impairment equivalent to that seen in the current study at a blood alcohol concentration of 0.1%. Furthermore, shiftworkers often accrue a cumulative sleep debt as a result of successive days of sleep loss. It may therefore be useful to expand the current protocol to include this type of cumulative sleep loss (Tilley *et al.*, 1982; Javanis *et al.*, 1990). This could be approached in different ways, for example by simulating shiftwork in the laboratory and measuring the performance impairment across the workweek while in another condition using the same subjects but measuring performance while intoxicated.

There may also be problems equating the performance impairment at night due to sustained wakefulness with performance impairment during the day due to alcohol intoxication. Performance is influenced by many factors including the time-of-day testing is carried out (Colquhoun, 1971). As a result of circadian rhythms performance is typically lower at night and higher during the day anyway. For this reason we may be under estimating the equivalent performance impairment between alcohol intoxication during the day and performance following sustained wakefulness at night, but over estimating the effects of sustained wakefulness on performance during the day.

Furthermore, the effects of sustained wakefulness on performance and the time-of-day or circadian factors are probably not equally additive. For example, if performance is impaired at night by 10% due to sustained wakefulness and 10% by circadian influences, the end performance decrement is probably not 20%. It may be more like 12-15 %, although it would be difficult to determine whether this was due primarily to time-of-day or sustained wakefulness, although the majority of the decrease is probably from the circadian influence. Similarly performance impairment due to alcohol intoxication in the morning with short prior hours of wakefulness would be better than performance while intoxicated at night following many hours of prior wakefulness. Again the influence of time-of-day, alcohol and prior hours of wakefulness are probably not additive but will most likely have some interaction to alter performance and therefore the ability to accurately quantify the relative risk.

Yet another consideration of this study is that the level of stimulation of an environment can alter the level of performance impairment seen due to sleep loss (Dijkman *et al.*, 1997). In a shiftwork environment the degree of stimulation may vary considerably. A truck driver may have social stimulation with other drivers via the radio or with a partner in the cab or be in an environment lacking stimulus like solo driving across the desert. Another example of the environment acting as a stimulus may be physicians working under emergency conditions where stimulation may be quite high compared to working on patient records in a quiet office. These specific conditions could alter the performance impairment observed due to sleep deprivation and may therefore, have some relevance to making assumptions about the level of sleep deprivation required to impair performance to an alcohol equivalently dangerous level. It may, therefore, be useful to conduct an experiment that varies the level of stimulation in the environment or the task. Previous research suggests that there is complex relationship between task complexity and interest level. It is commonly held that simple monotonous tasks are most sensitive to sleep loss. However, it may take greater hours of wakefulness before you see a significant impairment in interesting but complex tasks compared to simple but boring tasks like that used in the current study and other studies of sleep deprivation (Johnson, 1982). It could be assumed that it would take more hours of sustained wakefulness to reach an impairment level equivalent to that seen at a blood alcohol concentration of 0.1% if the task was complex and motivation increased.

Some comparison of the impairment associated during shiftwork can be made with the results from the study described in chapter five, which uses the same performance task. In Chapter five during a 12-hour shift rotation performance was measured hourly using the same task as in chapter two and the performance on the first night shift can be compared to the sleep deprivation condition in chapter two. This comparison including the difference between younger and older subjects will be discussed in detail in the discussion of chapter five.

Another consideration is that the performance test used in the current study has proven to be sensitive to sleep deprivation, alcohol (chapter 2), and melatonin administration (Rogers *et al.*, 1998). This is important in the sense that short duration testing procedures appear to be just as useful as longer testing procedures in detecting performance impairment associated with sustained wakefulness. Similarly, Dinges and colleagues concluded that tasks of 10 minutes duration were able to accurately detect the effects of sleep loss (Dinges, 1997) and Wojtczak-Jaroszow *et al.*, (1978) found reductions in performance using a series of three, one minute tasks. This has important implications for performance in a shiftwork setting, as longer performance tasks may interfere with normal workplace functioning and reduce worker motivation to complete the tests.

Regardless of the limitations of the current study, it has proved useful in educating industry and the community about the relative risks associated with extended hours of wakefulness. There has been much community, industry and academic discussion about the usefulness of the type of information contained in this study following its publication.

8.3 Experimental Section Two

Measuring Sleep and Performance During Simulated Shiftwork.

The study presented in chapter three compared actigraphy and EEG, chapter four sleep during a simulated 12-hour shift rotation and chapter five performance across each shift during the same protocol. For all three chapters variables were compared between younger and older subjects and between day and night.

8.3.1 Chapter Three

The Correlation between Actigraphy and EEG.

Quantitative studies to determine the duration and quality of sleep in shiftworkers have typically been restricted to using subjects in laboratory settings or invasive monitoring in the field (Torsvall and Akerstedt, 1987: Foret and Latin, 1972; Tilley *et al.*, 1981; Foret and Benoit, 1974). Although several studies have examined the correlation between nocturnal PSG and activity measurement in both normal and patient populations (Sadeh *et al.*, 1995), validation studies of actigraphically measured sleep in shiftworking populations have not been reported.

The aim of this study was to determine the correlation between wrist actigraphic and EEG measures of sleep/wake activity during a simulated shiftwork protocol. In particular we were interested in determining whether there were significant differences between day and night-time sleep periods and between older and younger subjects. Subjects wore a Gaehwiler wrist activity monitor for 6 consecutive days and data was collected in 30-second epochs. Many other studies comparing EEG and actigraphic techniques have typically used sampling periods one minute or greater (Mullaney *et al.*, 1980; Sadeh *et al.*, 1995). The 30 second epochs used in the current study may reduce the epoch for epoch match compared to other studies that use longer epochs. Furthermore, wrist actigraphy is typically scored by an algorithm rather than hand scored. One limitation of these algorithms is that they are not specifically developed for use in a shiftwork setting.

Developing an algorithm specific to shiftworkers may make the accurate detection of sleep periods using actigraphy easier. From previous studies we know that as the probability of sleep decreases so does the accuracy of wrist activity monitoring in detecting sleep/wake (Levine *et al.*, 1986). In the current study we found similar results, in particular the accuracy or validity of wrist actigraphy was the lowest for older subjects during the day-time. Therefore, any algorithm may have to be varied for older and younger subjects as well as being able to incorporate the ability to determine day-time sleep and night-time sleep. The information in the current study could be used to create just such an algorithm.

In the current study the correlations between EEG and actigraphically recorded day-time sleep were similar to that found in insomniacs (Hauri *et al.*, 1992; Sadeh *et al.*, 1989). The use of wrist actigraphy in determining sleep/wake activity in shiftworkers should be used with caution particularly for specific measures such as sleep efficiency. Nevertheless actigraphy appears to be valid in determining sleep duration, at least for longer sleep periods although it is yet to be proven that it is valid for naps. Some research suggests that short sleeps of less than 15 minutes are difficult to accurately determine with activity monitoring (Cole *et al.*, 1992; Sadeh *et al.*, 1995).

Activity monitoring using this model of actigraph is clearly a valid measure of sleep/wake activity, compared to EEG recorded sleep. However, in the current protocol EEG and actigraphy were only compared when subjects were in bed in the laboratory and so field studies may be useful to determine the validity and reliability of actigraphy in a less controlled environment. Specifically it may be useful to have subjects wear activity monitors while having their sleep measured by EEG in their normal sleeping and working environment. This would help determine the usefulness of this technology in the environment in which it is most commonly used, people's homes.

Taken together the results of the current study suggest that while activity monitoring using the Gaehwiler actigraph correlated well with EEG for most measures some caution is warranted for more specific measures such as sleep efficiency particularly in older subjects. It is also important to point out that if other brands of actigraphs were used the correlation may have been very different, since the sensitivity and design of monitors varies between manufacturers.

8.3.2 Chapter Four

Age-related Differences in Sleep During Reduced Psycho-social Conditions.

Chapter four examined the effects of a simulated 12-hour shift rotation on sleep duration and quality in younger and older subjects. This analysis may also provide an opportunity to clarify why the correlations between EEG and actigraphy varied between day-time sleep periods for each age group by establishing how sleep varied between shifts and between subject groups.

Sleep Duration

It was found that sleep was significantly altered during a 12-hour shift rotation and that the degree of disruption was significantly different between younger and older subjects. Day-time sleep durations for the younger subjects and for the first day-time sleep period for the older subjects, were, as long if not longer than the night-time sleep periods. The night-time sleep durations were, however, considerably shorter than would typically be observed (5.6 hours versus 7-8 hours), so that although sleep periods were of a similar duration (day and night) they were in most cases comparatively quite short.

The combination of the circadian rhythm in sleep-wake and the work schedule act to alter the normal sleep-wake pattern of these subjects, resulting in considerably shorter sleep than "usual". Previous studies have found that early morning starts of as late as 0700 hours result in shorter night-time sleep because subjects did not alter their habitual bed times (Kecklund *et al.*, 1997). This was possibly the result of both circadian and psycho-social factors (Walker, 1985, Czeisler *et al.*, 1980). To some degree this is probably also the case in the current study because although the subjects were in the laboratory they still socialized among themselves, although we assume that the effect of psycho-social factors in the current study are much less than that seen in the field.

The longer day-time sleep period following the first night shift compared to that following the second night shift may be the result of homeostatic factors, as there were longer hours of prior wakefulness. This may in part account for the shorter day-time sleep following the second night shift. Prior to this sleep period, the hours of prior wakefulness were significantly shorter than prior to the first day-time sleep period. Finally this sleep period may have been curtailed due to the subjects not having to work that night and in an attempt to return to their normal nightly sleep periods they woke earlier. Anderson and Bremer (1987) report results similar to those in the current study showing that while sleep following the first night shift is adequate, subsequent day sleep and particularly sleep following the last night shift are shorter (Knauth and Rutenfranz, 1981). It is difficult to determine the relative contribution from each of these factors to when and how long these subjects slept during the 12-hour shift rotation. Some insight may be gained from other studies under differing experimental conditions.

In a field-based setting using experienced shiftworkers on an oil rig Parkes (1994) reported longer day-time compared to night-time sleep periods, compared to workers on shore. Both groups of workers had 12-hour shift schedules, offshore work involved seven 12-hour days followed by seven 12-hour night shifts while onshore work varied between fast and slow rotating day and night work. The offshore workers may have slept longer during the day because they knew they had to work for two solid weeks before they got a break. This combined with reduced social and environmental distractions may have lead to the increased day-time compared to night-time sleep duration in this group. Alternatively it could be a result of experience in this type of shift schedule. It is not clear, however, whether the workers were able to maintain this level of sleep duration for the entire week. Parkes (1994) did not present daily scores so it must therefore be assumed that these workers slept consistently longer during the day compared to the night for the duration of the study.

It is unlikely that the longer day-time compared to night-time sleep periods in the current study or that by Parkes (1994) were due primarily to an adaptation to the shift schedule, although some adaptation would have occurred. In a more recent study of offshore oil rig workers, Barnes *et al.* (1998) reported that across a 2 week series of night shifts workers took approximately 8-10 days to adapt their melatonin rhythm to the work schedule.

Isolation of the environment in the Parkes (1994) study does not explain why in the study by Budnick *et al.* (1994) and Rosa *et al.* (1989) in which workers who were not isolated and catered to like those in the Parkes (1994) study still slept more during the day-time compared to the night-time on a 12-hour shift rotation. For the Budnick study it may be because the workers had an early morning start time (0600 hours). However, in comparison subjects in the Rosa study (0800 hours) started two hours later with the same result of an approximately a one hour increase in day-time compared to night-time sleep. It also does not explain why in most other studies of 12-hour shift rotations subjects sleep more at night than during the day-time (Frese *et al.*, 1984; Rosa, 1991; Parkes, 1994; Smith *et al.*, 1998). It is difficult to say exactly why in the current study day-time sleep was longer or the same as night–time sleep periods other than it was a combination of circadian, homeostatic and psycho-social factors. However, considering that the psycho-social factors in this study were minimized they would have probably had little or no influence on sleep.

Besides the studies of 12-hour shifts schedules, studies that inverted the sleep-wake cycle have not observed the shortened day-time sleep durations characteristic of most night shiftworkers (Webb *et al.*, 1971; Berger *et al.*, 1971, Taub *et al.*, 1973). These studies may provide a clue to why in the lab and some field studies no drop in day-time sleep durations on 12-hour shifts are observed. Tilley *et al.* (1982) suggested that it may be because shiftworkers are generally on average considerably older than the subjects used in sleep inversion studies. In the current study this may partly be the case. Results of the current study indicated that while the older subjects slept about the same for the first day-time sleep period compared to the night-time sleep periods, that for the second day-time sleep period they slept significantly less, while the younger subjects slept longer or the same during the day as they did at nights (see chapter four). So for the older subjects the results were more typical of those observed in field based studies of shiftworkers where day-time sleep following the night shift is shorter than the night-time sleep periods (Foret and Lantin, 1972; Tilley *et al.*, 1981; Torsvall *et al.*, 1981, 1989; Akerstedt *et al.*, 1991a; Rosa, 1991; Frese *et al.*, 1984; Akerstedt *et al.*, 1991a; Parkes, 1994).

Further studies of experienced shiftworkers of different ages both in the laboratory and in the field where environmental social and domestic distractions are controlled would be important in determining the significance of these factors in the sleep of shiftworkers. Studies looking at shiftworkers in isolated places, for example oil rigs or other mining operations may be the closest thing that a researcher can get to this type of control in the field. There is also a need to look at the influence of these factors and different 12-hour schedules on sleep, for example seven consecutive day or night shifts.

Sleep Architecture

Previous studies have shown that there are significant differences in sleep architecture between day and night sleep periods in shiftworkers (see Akerstedt, 1995b). They have also shown that there are significant differences in sleep architecture between older and younger subjects, such that sleep is shorter, more easily disrupted, more fragmented and lighter (Prinz, 1995; Miles and Dement, 1980; Carrier *et al.*, 1997; Dement *et al.*, 1982) and the same can be used to describe the day sleep of a night worker (Akerstedt, 1985b). During day-time sleep periods of a shiftworker stage 2, REM, and sleep latencies are reduced, while stage 3 and 4 are unaltered, and REM periods occur earlier in the sleep period (Akerstedt *et al.*, 1991a). Therefore, while the duration of day-time sleep periods, in the current study, may be longer/shorter or the same they may be of less restorative value.

In the current study sleep efficiencies for the older subjects were significantly lower during the day-time compared to the night-time sleep periods. Furthermore, sleep efficiency for the older subjects was on average significantly lower compared to the younger subjects. There was also a clear increase in stage 0, 1 and 2 sleep during the day-time for the older subjects compared to the younger subjects and compared to their night-time sleep periods. Torsvall and colleagues (1981) reported that day sleep for older shiftworkers included relatively more stage changes, awakenings and stage 1. Similarly, the older subjects in the current study spent more time in stage 1 during the day-time compared to night two and significantly less time during the day in stage 2 sleep compared to younger subjects and compared to night-time sleep periods. In addition, delta sleep (stage 3 & 4) for the older subjects was significantly less than the younger subjects for all except one sleep period (night 3). This is not surprising as older individuals typically have less delta sleep than younger subjects during night-time sleep periods (Dement *et al.*, 1982; Bliwise, 1993, 1994). The increase in stage 1 and 2 sleep during the day-time sleep periods of the older subjects in the current study is comparable to the night-time sleep of subjects approximately 60 years of age (Miles and Dement, 1980). It appears therefore, that sleeping during the day has effectively "aged" the sleep of these middle-aged subjects. In comparison, the younger subjects showed significant changes in delta and REM sleep, as well as a decrease in day-time sleep efficiency.

The increases in the lighter sleep stages (stages 1 and 2) for the older subjects is interesting in that these are the stages from which sleep is more easily disturbed

(Rechtschaffen *et al.*, 1966). This may mean that under normal sleeping conditions (i.e. at home or on site) the older workers are more susceptible to sleep disruption from family, traffic, or bird noises in their sleeping environment. This could further increase the time spent awake (stage 0) in bed that was observed in the current study for this group of subjects and be of some importance considering the reduction in sleep duration and efficiency for the older compared to the younger subjects for both day-time sleep periods. When this reduction in sleep is combined with lower general performance levels (Webb and Levy, 1972; Davies *et al.*, 1992) and the possibly greater sensitivity to sleep loss (see Chapter five) of the older subjects, significant performance impairments may be expected above those reported for younger subjects. The influence of this reduction in sleep on performance is discussed in the next chapter.

When taken together the results of this study suggest that in a laboratory environment, under optimal conditions with reduced psycho-social input that sleep during the day in younger and to some degree older subjects may be as long if not longer than night-time sleep when on a 12-hour shift rotation. In addition, the significant difference in sleep duration between younger and older subjects during the day-time suggests that the older subjects are not able to cope as well as the younger subjects with sleeping out of phase, and/or with the 12-hour compression of the work week. They also suggest that prior hours of wakefulness plays an important part in determining sleep duration. Therefore, it seems that sleep duration and architecture in shiftworkers is influenced by a combination of circadian, homeostatic, age and competing psycho-social factors.

Furthermore, research may be required to determine if these changes in sleep architecture during the day result in sleep being of less restorative value, even if the duration of sleep is sufficient.

8.3.3 Chapter Five

Comparing Performance on a Simulated 12-hour Shift Rotation in Young and Older Subjects.

By measuring performance using an unpredictable tracking task at regular intervals during work periods it was possible to look at neuro-behavioural performance during a simulated 12-hour shift rotation. Performance of the older subjects on this task began significantly lower than for the younger subjects and also showed a greater reduction across shifts. Whether this was the result of a greater sensitivity to sleep disruption, time-of-day effects, lower motivation on the task or less experience with computers is not clear.

Overall there was no significant difference in performance between day and night shifts, however, across trials in each shift there was a positive correlation for performance during the day shifts and a negative correlation for performance on the night shifts. During the early hours of the morning, performance was lower regardless of whether it was at the beginning or the end of the shift for the older subjects. When prior sleep duration and prior hours of wakefulness were considered it appeared that to some degree, hours of prior wakefulness and particularly circadian influences may be of central importance in determining performance on this task. However, due to the limited rage of these measures (prior sleep duration and prior wakefulness) it is difficult to make any definitive conclusions.

From the current study there appeared to be only a minor influence of sleep reduction on subsequent performance. The major contributor to impaired performance was the time-of-day that the test was completed, particularly for the older subjects. However Tilley *et al.* (1981) have shown using a different task (simple reaction time) that there was a significant decreases in performance during a course of consecutive night shifts. Therefore the number of days that sleep is reduced could play a significant role in the level of performance decrement that is seen, as would the type of task measured.

This kind of simulated shiftwork study could be used to determine the influence of sleep reduction on performance. As was discussed in the introduction of this thesis, performance reductions during shiftwork are often inferred from studies of sleep deprivation or restriction. These studies have shown that reduction or restriction of nocturnal sleep to 4-5 hours duration may lead to significant reductions in performance and alertness (Dinges *et al.*, 1997). It is difficult, however, to translate the impairment in day-time functioning in these studies to the night-time functioning and day-time sleep reduction reported in shiftwork studies, as the sleep reduction reported in shiftworkers is typically day-time sleep and subsequent performance during the night-time.

It may, therefore, be useful to restrict day-time sleep durations and determine the subsequent performance impairment on night-time functioning, to determine how many hours of day-time sleep are required before significant performance impairments are reported above those seen as a result of the circadian rhythm in performance. This is a complicated issue, as prior hours awake, prior hours of sleep and time-of-day are all going to influence the ability to sleep and subsequent performance. It may be difficult to conduct a study where sleep duration during the day is varied because sleep is typically more difficult to maintain during the day-time. Although the results from the current study suggest it may be possible to vary sleep length during the day, it may be difficult to maintain this. Subjects may begin to adjust to the new day-time sleep and further complicate the interpretation of this type of study. If sleep is restricted only for a few days this may reduce the influence of the adjustment factor, but it may also mean that performance decrements above those seen for circadian rhythms do not become evident.

Regardless of the difficulties in conducting this kind of study, the results may be useful in determining how much day-time sleep is required before night-time performance is reduced further as a result of circadian rhythms. The degree, to which the sleep reduction during shiftwork exacerbates the performance impairment seen from time of day effects is further complicated by the partial adjustment to a shiftwork schedules that may occur over successive shifts in turn making it difficult to determine what proportion of the impact each of these factors has on performance. There is a need for more well designed studies that measure performance at different times of day and with different levels of wakefulness and prior sleep. Perhaps the best way to do this would be to either simulate studies in the laboratory using experienced shiftworkers or to carefully measure performance in the field.

It is important to determine whether sleep loss in the older subjects does translate into a significant decrease in performance above that already reported due to night or 12-hour shifts. There is some evidence to suggest that sleep need decreases with age (Pollack *et al.*, 1994). If sleep need decreases so also may the impact of sleep loss on performance. There is some evidence from sleep deprivation studies that suggest this may be the case. Brendel *et al.* (1990) and Bonnet (1989) reported that while performance is reduced due to sleep deprivation in both older and younger subjects, the performance of older subjects appeared to be less sensitive to the effects of sleep loss. In the current study, the performance of the older subjects appears to be influenced more by time-of-day. While performance in the younger subjects maintained a fairly constant level across both day and night-time shifts, performance in the older subjects varied across all shifts. This may be the result of several factors including a general reduction in arousal levels, altered sensitivity to sleep loss or time-of-day influences on performance or simply due to less familiarity with computers or less motivation to perform this type of task for the older subjects.

However, this does not explain why there was no significant change in performance across shifts for the younger subjects, except on the first night shift when a significant negative r^2 value was reported which was probably the results of the extend hours of wakefulness. Even for the younger subjects you may expect there to be a significant reduction in performance across the second night shift. This may be a consequence of the task itself but considering that the task has proven useful in detecting performance impairment to alcohol, melatonin and sleep loss this is unlikely. Although, all of these studies were conducted only on younger subjects. For the older subjects the interaction effect between shift and trials explains why on average there is no difference in performance between night and day shifts (i.e. on average performance increased across the day shifts to the same degree that it decreased across the night shifts).

The influence of shiftwork experience or experience on the task being measured also needs to be considered. Gillberg *et al.* (1996) reported that the performance impairment on simulated driving was significantly influenced by both shiftwork and driving experience. Shiftwork experience of the subjects in the current study was minimal or non-existent so it is difficult to say whether or not this would have had an influence. Because there is a clear distinction between the older and younger group this would suggest that the differences in sleep and performance were due to age-related differences rather than to shiftwork experience.

Considering the current study was conducted under optimal conditions, there may be greater differences in sleep and performance between the older and younger subjects when in a real world setting. To determine the influence of shiftwork on the sleep and performance of shiftworkers and the influence of experience or age it may be necessary to carry out longitudinal studies, following individuals across the working life. The ability to conduct this type of study, however, is extremely limited.

An important aim of this thesis was to be able to equate the performance impairment seen with sustained wakefulness as a blood alcohol concentration equivalent. The same performance task was used in Chapters two and five. Therefore, it is possible to compare performance in both studies between 13 and 25 hours of wakefulness. In the following section the results from the study reported in Chapter two will be compared with the performance on the same task of the older and younger subjects in the current protocol for the first night shift.

Comparison of Performance in Chapters Two and Five

Differences in the performance decrement observed on the first night shift in the current study (Chapter five) were seen when compared to the results of the sleep deprivation study in Chapter two. Performance during the sleep deprivation study was reduced by approximately 8.5% between 13 and 25 hours of wakefulness. In contrast, during the simulated 12-hour shift rotation the performance impairment during the first night shift, which was also between 13 and 25 hours of wakefulness, was between approximately 4-6%. Specifically, the performance impairment for the young subjects was approximately 4% and for the older subjects approximately 6%. The 2.5-4.5% variation in performance decrement between these studies may be the result of sampling frequency. Subjects in the sleep deprivation study were tested at half hourly intervals for 28 hours, while in this study (Chapter 5) they were tested less often at hourly intervals for 12 hours. The greater number of tests completed prior to 13 hours of wakefulness in the sleep deprivation protocol may have led to decreased motivation, combined with the prior hours of wakefulness, thereby increasing the performance decrement. To help visualise the performance impairment differences between the two studies figure 1 was created.

If the sampling frequency was at least in part responsible for the lower performance reported in chapter 5 compared to chapter 2 it may have serious implications for studies of the circadian rhythms in performance, such that sampling frequency may alter the amplitude of the rhythm that is being measured. For example the amplitude of the rhythm may be a higher if performance was measured frequently because the variation in performance would be greater. However, this variation would have little to do with the circadian rhythm of performance.

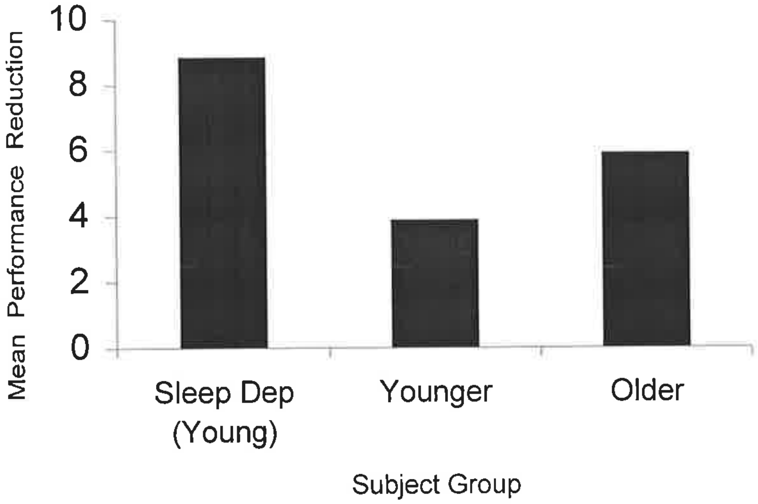


Figure1. A graphic representation of the percentage reduction in performance between 13 and 25 hours of wakefulness, from the sleep deprivation condition in chapter 2 and from both the younger and older subjects on night shift one from chapter 5.

Another important implication of the comparison between chapter two and five is the difference in performance between the older and younger subjects. As a result of the greater reduction in performance in the older compared to the younger subjects in chapter five it is possible that we may be underestimating the performance impairment equivalent (to alcohol) for older individuals as the study in chapter two was conducted on younger subjects only. Although the performance difference was lower in the shiftwork study this may be due to methodological differences. Older subjects may also have different performance decrements in response to alcohol compared to the younger subjects. Regardless of the difference in the level of the decrease in performance between chapter 2 and 5 there was still a significant reduction in performance above that seen at a blood alcohol concentration of 0.05%.

This comparison highlights the usefulness of studies that directly compare the performance impairment in shiftwork and other conditions with that of alcohol concentrations. There are, however, several factors that should be taken into consideration, for example the influence of multiple performance testing (frequency of performance testing) on motivation and the amplitude of performance changes and different types of tasks (for example a whole battery of cognitive tasks or simulator tasks) should also be considered.

Circadian Effects on Performance Comparison of Chapter Two and Five

It could be argued that looking specifically at performance between 10-26 hours of wakefulness in Chapter two is maximising the effects of sustained wakefulness, as there would be both an influence of the circadian system and sustained wakefulness at this time. The rationale for analysing the data in this way was that shiftworkers are typically both awake and have had a similar length of prior wakefulness at this time of day and would therefore in principal be performing at a similar level. Although in the field it is possible that individuals would have varying lengths of prior sleep and this too could influence performance. In the current study giving the subjects the same opportunity to sleep in the laboratory the night before the protocol, at least in part controlled for the influence of prior sleep length.

It could also be suggested that part of the increase in performance seen in the alcohol condition at low blood alcohol concentrations (between 0800-1600 hours) was due to an increase in performance as a results of the circadian system. This suggestion could be supported by the results from the older subjects in Chapter five that show that performance during the day-time on a 12-hour shift improves significantly across the same time period (0800-1600 hours) $R^2=0.67$ ($p=0.0001$). However, both the young subjects in the 12-hour shift study and the young subjects in the alcohol condition in chapter two show no significant $R^2=0.10$ increase in performance between 0800-1600 hours (see Figure 2 and 3). This supports the suggestion made in the earlier discussion of Chapter Five that the older subjects appear to have a strong circadian influence on performance compared to the younger subjects during this time. Alternatively this discrepancy between older and younger subject could be explained by a learning effect. However, that does not explain why you see the same thing on day shift two, and a significant reduction in performance across both the 12-hour night shifts in the older group but not in the younger group. The performance decrement observed in the alcohol condition described in chapter two, at least in younger subjects is likely to be a result of the effects of alcohol intoxication on performance rather than circadian rhythm variations in performance. If the same study were to be conducted on older subjects, there may be a significant effect of circadian rhythms on performance during the day-time, as in the 12-hour shift study reported in chapter five.

To clearly illustrate the relationship between performance in the alcohol and sustained wakefulness condition at the same time of day and address any concerns about the circadian influence on performance, figure 3 was created. What this figure clearly shows is that there is a significant reduction ($R^2=0.82$, $p=0.0001$) in performance between 0800-1600 hours in the alcohol condition, but no significant change in performance in the sustained wakefulness condition between (0800-1600 hours, $R^2=0.1$). In addition, in the sustained wakefulness condition performance does not significantly differ from the baseline levels. This suggests that the reduction in performance in the alcohol condition is due to the increasing level of alcohol intoxication across time between 0800-1600 hours and is not significantly influenced by the circadian rhythm of performance.

Another criticism of the study described in chapter two could be the comparison of performance at differing levels of alcohol intoxication between 0800-1600 hours with the performance impairment between 1700-0900 hours following 10-26 hours of wakefulness. The justification for making the comparison in this way was to eliminate the effects of prior wakefulness in the alcohol condition and simply look at the effects of alcohol intoxication. While the influence of the circadian system is noted, it would be very difficult if not impossible to eliminate the influence of this system on performance completely. It is possible that at different times of day, performance impairment at the same blood alcohol level would vary due to the circadian influence on performance. That is why I suggest that it is difficult if not impossible to generalise the findings of this study to any other times of day or varying durations of prior wakefulness.

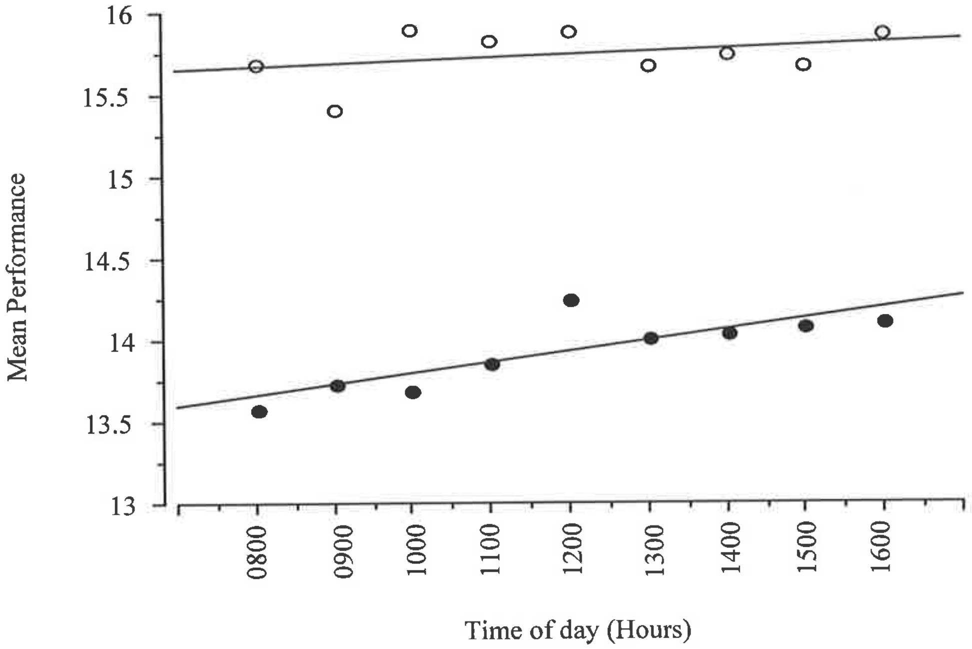


Figure 2. Regression plots of mean hourly performance in both older (closed circles) and younger subjects (open circles) between 0800-1600 hours on a 12-h shift that was from 0700-1900 hours. The $R^2 = 0.67$ ($p=0.0001$) for the older subjects and the $R^2 = 0.10$ for the younger subjects between 0800-1600 hours.

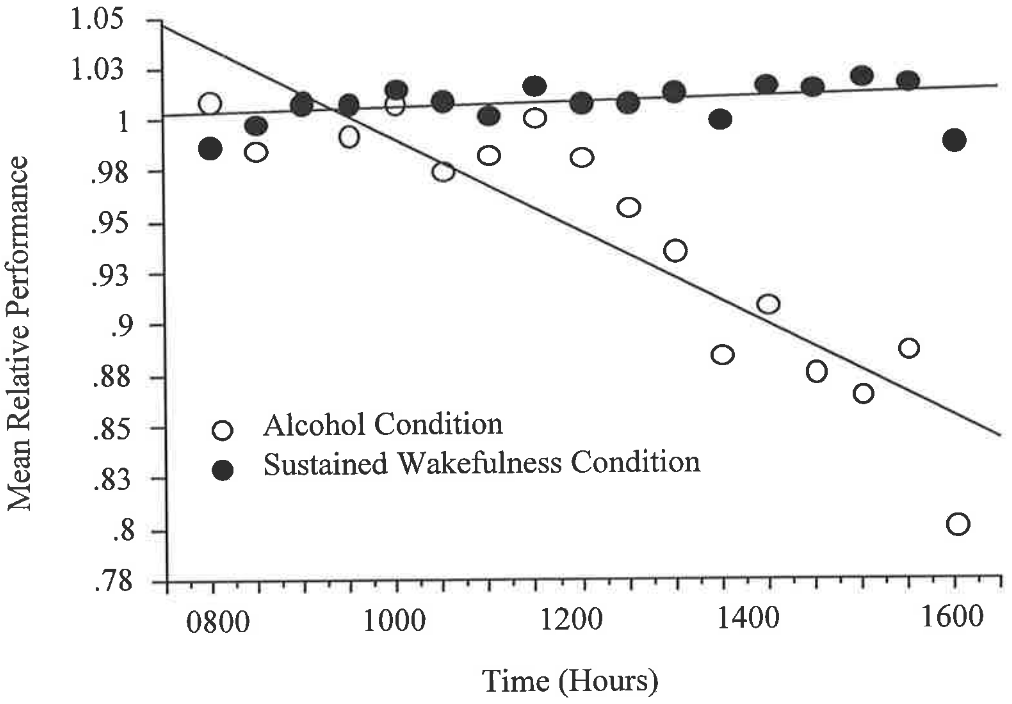


Figure 3. Regression plots of mean relative performance between 0800-1600 hours in the sustained wakefulness (closed circles) and alcohol (open circles) condition. The $R^2 = 0.82$ ($p=0.0001$) in the alcohol condition and the $R^2 = 0.10$ in the sustained wakefulness condition between 0800-1600 hours.

8.4 Experimental Section Three

Field-based Assessment of Sleep-wake Behaviour of Drivers on Irregular Shiftwork Schedules.

This section considers some of the results obtained from a series of 14 field-based trials carried out in the Australian Rail Industry. The results discussed in this section are an average of all the sleep and work periods from all depots recorded using sleep and work diary techniques. In addition, to sleep diary techniques sleep was recorded using actigraphy. Performance was recorded at the beginning and at the end of each shift and 6-sulphatoxy melatonin levels were measured in urine collected during the sleep periods. It is beyond the scope of this thesis to report all the findings of the field-based studies in any detail and for this reason only the sleep and work data is reported in Chapters six and seven.

These studies indicated that on average the sleep/wake patterns of this group of train drivers did not adapt to their irregular work schedule.

Out of the 253 drivers who participated in this study 249 were male and only 4 were female. Although the number of female participants is low, in most cases all the female drivers within a depot participated in the study. Two of the women were from freight depots and two were from passenger depots. The Australian rail industry is male dominated with only a few women drivers country wide and so it was not possible to draw any conclusions about gender differences and adaptation to this type of irregular work schedule.

The average (± s.d.) age of the drivers was 39.7 (± 6.8 years) years and with few younger than 30 years of age and none above 60 years of age. The lack of drivers below 29 years of age is probably a result of the length of training involved to become a qualified train driver. It may have also been because the younger drivers chose not to participate in this study, however, from our knowledge of the depots involved in the studies the range of ages of subjects who volunteered was representative of the industry. Many other shiftwork related studies have reported similar mean ages of participants of around forty years of age (Foret and Lantin, 1972; Kecklund *et al.*, 1997; Tepas *et al.*, 1993; Lee, 1992; Tilley *et al.*, 1981).

With the techniques used in these field studies we were able to collect useful and reliable information from a large number of subjects. I believe that this was primarily due to constant experimenter support and the building of a rapport with the workers at each depot, suggesting also that our aim of designing the protocol to be as unintrusive as possible to maintain driver participation was successful.

8.4.1 Chapter Six

Sleep of Train Drivers Working Irregular Schedules

The results from the sleep and work diaries collected in these studies indicated that the circadian rhythm in sleep propensity was strong (in the sense that rhythm in sleep/wake did not shift quickly) and that a nycthemeral sleep/wake pattern (sleep at night, active during the day) was maintained even in drivers working highly irregular schedules.

Previous studies have examined the influence of irregular hours of work in train drivers in Europe and the United States (Heitmann *et al.*, 1997; Hak and Kapman, 1981; Foret and Lantin, 1972). Recently Heitmann *et al.*, (1997) reported that like the drivers in Australia the train drivers in North America on irregular schedules also slept less during the day than at night and that drivers slept less on days on, compared to days off. Similarly, the drivers in the current study slept 1-2 hours less per workday and tended to "catch-up" sleep on days off. Foret and Lantin (1972) recorded sleep using both EEG and sleep diary techniques and found that sleep duration was reduced on work days when compared to days off and that the length of sleep was a function of the time of sleep onset.

Although the scheduling of shifts in North America appears to be as irregular as in the Australian rail industry (see Figure 1 chapter six and Heitmann *et al.*, 1997), they allocate shifts very differently. This may in turn influence the adaptation of these drivers differently from drivers in the Australian rail industry. In most cases train drivers in Australia have between 2 days to 2 weeks notice of their shifts while in the U.S.A drivers work on an "on call" type basis. If drivers are not sure when their next shift is going to be it may make it more difficult to organize their day to sleep at the best possible time. As a consequence drivers may be forced to sleep immediately after finishing work to ensure that they actually get some sleep between shifts and this may in turn reduce sleep duration due to circadian factors. Because of the circadian rhythm in sleep propensity (Lavie, 1992; Richardson *et al.*, 1978; Carskadon and Dement, 1977; Sugerman and Walsh, 1989) different sleep strategies may either increase or decrease sleep depending on the time-of-day that the drivers is trying to sleep. It may be useful to be able to quantitatively compare the results from both of these studies and driver behaviour as a consequence of these differences.

In contrast to several studies that report significant differences in sleep as a result of psycho-social factors and domestic situations (Folkard *et al.*, 1978; Lee, 1992; Walker, 1985), in the current study, individual and demographic factors appeared to play only a minor but significant role in influencing the timing of sleep. These factors may be more of an issue in other groups of shiftworkers, because this group of predominantly male train drivers anecdotally report that they did not spend a lot of time with their families during work periods. In comparison, Dekker *et al.* (1993) in a survey of train drivers and their spouses, showed that both groups slept approximately 92 minutes less on days on compared to days off.

The reduction in sleep on days on compared to days off may be the results of drivers attempting to catch up on sleep on days off. Alternatively due to the sometimes short length of the break between consecutive shifts drivers may still have to fit in other social and domestic responsibilities between shifts and therefore time is taken away from sleep. Although in this group domestic situation for example marital status and children in the house had a minor effect on the sleep-wake pattern, in other shiftwork populations there may be a greater impact of social and domestic factors, for example in nursing (Lee, 1992; Folkard *et al.*, 1978).

In comparison to the difference between older and younger subjects in the laboratory study discussed earlier there was no significant difference in the amount of sleep between the older and younger subjects in the current study. There was, however, a significant difference in the timing of sleep in the older compared to younger subjects in this study.

In addition to the changes in sleep due to psycho-social factors there may be differences in sleep depending on the timing of the shift. For example Hak and Kapman (1981) studied a group of Dutch train drivers on an irregular schedule using diary techniques. In this group of drivers they found that sleep prior to an early shift was significantly shorter than following a late or night shift. Similar findings were evident in the current study, the only exception being for late shifts. Hak and Kapman (1981) reported drivers obtaining 8.3 hours of sleep following late shifts while drivers in the current study had 7.4 hours of sleep. Hak and Kapman (1981) concluded that the sleep duration of train drivers on irregular schedules was significantly reduced and that the schedules worked by these drivers were unacceptable due to the physical and mental stress that they produced.

Previous research has shown that sleep durations following night and early morning shifts are typically shorter than for those during the day or afternoon (Tilley *et al.*, 1982; Folkard and Barton, 1993b; Tepas *et al.*, 1990; Akerstedt, 1994; Frese *et al.*, 1984; Kecklund *et al.*, 1997; Akerstedt *et al.*, 1991a, b). In the current analysis we report the amount of sleep (rather than duration) on an average day, which includes major sleep periods and naps, rather than simply average sleep duration. From the current analysis it is difficult to estimate napping behaviour, however, napping appears to be used primarily for shifts when a break begins at around mid-day (see chapter seven figure 2).

Another interesting aspect of this study was that the timing of sleep across the 24 hour day in relation to work and sleep was different from the sleep/work/off-time reported by Tepas *et al.*, (1993). From a study that they reported in 1981, shiftworkers on regular rotating schedules (for example night, day, afternoon shifts) had a distinct pattern of work, leisure and sleep across the 24-hour day (see Figure 2 in Chapter one). Tepas *et al.* (1993) reported that shiftworkers slept prior to work for both day and afternoon shifts but that for the night shift, workers slept immediately following work and had leisure at a similar time to day workers. Workers in the current study rarely had a set starting time, particularly for the freight train drivers (see figure1 chapter 6). This was a result of customer demand and shift start times varying by several hours. Unlike the workers in the current study the workers in the study by Tepas *et al.* (1981) had set starting times and consequently there are some differences in the timing of sleep between these two studies. For example in the current study drivers were most likely to sleep at night no matter what shift they were on. Although some did sleep during the day it was proportionally less than those sleeping at night.

Rather than examining specific shifts the current study considered sleep for predominant shift types, for example morning shifts. Drivers on predominantly morning shifts slept significantly less than night, mixed or afternoon shift type drivers. Of more interest in the current analysis was the influence of irregular shift schedules on the pattern of sleep across an average day, which clearly showed that drivers spent proportionally more time sleeping at night than during the day.

Clearly if drivers were sleeping primarily during the night-time for most shifts then there must have been a significant reduction in sleep for breaks occurring during the day-time. Frese *et al.*, (1984) suggested that the main determinant of sleep length was the time allowed between consecutive shifts. With this in mind the following chapter attempted to determine the pattern of sleep as a function of break onset time and determine how much sleep a driver would accumulate depending on the duration and timing of a break.

8.4.2 Chapter Seven

The Effect of Break-onset Time on the Amount of Sleep Accumulated by Irregular Shiftworkers During Breaks Between Shifts.

In many industries, safety requirements specify minimum break durations between subsequent shifts. These requirements are based on the assumption that minimum breaks allow employees sufficient opportunity to sleep. However, there is a strong circadian rhythm of sleep, such that the majority of sleep occurs during night-time hours and little sleep occurs during the day (see chapter six). While this effect may be due in part to a strong internal circadian component of sleep/wake behaviour it is also most likely influenced by a strong diurnal psycho-social component as well. Thus, the amount of sleep accumulated during a break appears to be dependent on the time of day that the break occurs (chapter seven).

The results from this study indicate that the circadian rhythm of sleep is stable, but may be skewed for breaks beginning between 0400 hours and midday (see Figure 1, Chapter seven). Further, the rigid circadian rhythmicity of sleep influences the amount of sleep that is accumulated in time off work, such that time off during the night has a greater recovery value than time off during the day (see Figure 2, Chapter seven). Thus, breaks of minimum duration (8-12 hours in the Australian Rail Industry) occurring during the day may not provide employees with adequate recovery time.

It has not been common practice to take time-of-day into account when scheduling breaks, rather, the duration of the break has been the primary issue (Personal communication, Public Transport Union, 1997). What the current study shows is that the duration of the break should not be the only consideration when scheduling breaks to allow adequate recovery time. The next question is what would be considered adequate recovery time? How much sleep is adequate and should it be a duration of sleep or should it include factors like sleep architecture? Practically, sleep stages probably have little relevance from an industry perspective and duration of sleep may be more important for subsequent performance.

As mentioned previously in this discussion, while 4-5 hours of night sleep seems to be the limit before subsequent day-time performance is impaired (Dinges *et al.*, 1997) there is to my knowledge no equivalent for shortened day-time sleep and subsequent night-time performance other than limited shiftwork studies (Tilley *et al.* 1982; Tepas *et al.*, 1981). As has been shown in this thesis and by many other researchers, shiftworkers often experience shortened day-time sleep periods and night-time sleep prior to early morning shifts (Tilley *et al.*, 1982; Frese *et al.*, 1984; Folkard and Barton, 1993b), which has been associated with reductions in performance in many situations (Tilley *et al.*, 1982; Folkard *et al.*, 1976; Rosa and Colligan, 1988; Rosa *et al.*, 1985; Tepas *et al.*, 1981).

Sleep can be further reduced if the break between shifts is not of an adequate duration. Kuramatani *et al.* (1994) reported that time off between shifts was highly correlated with sleep duration and that a 16 hour break was optimal to be able to have approximately 7 hours of sleep. Furthermore other researchers suggest that time-off between shifts can also be influenced by commute time and family and social responsibilities (Knauth and Rutenfranz, 1982; Kogi, 1982). In the current study not only was the duration of the break taken into account but so also was the timing of the break. Since the drivers in the current study appeared to postpone sleep to a period of high sleep propensity (i.e. night-time) the 'time off' required to get 7 hours of sleep differed depending on when the break started. Clearly when breaks between consecutive shifts are a minimum of 11 hours in duration, drivers in the Australian rail industry will in most instances not be able to get 7 hours of sleep.

It is clear from the results presented in chapters six and seven that train drivers on irregular shifts are not altering their sleep/wake patterns to any great degree. Considering the impact of shortened sleep on performance it would be useful to determine what the lack of adaptation of the sleep/wake cycle to the irregular schedule does to subsequent performance at work. There is currently some interest within the

Australian Rail Industry to investigate measures of driver performance recorded on the train. One possibility is brake usage, which has been estimated to cost approximately $500/application and speed changes. Alternatively portable performance testing equipment like that used in the laboratory studies mentioned may be useful in determining the influence of prior sleep duration on driver performance.

Conclusion

In conclusion the results presented in this thesis suggest that sustained wakefulness of as little as 18 hours (starting at 0700 hours) has a significant influence on performance that is equivalent to the performance impairment induced by elevated blood alcohol concentration greater than 0.05%. Older subjects have reduced sleep during the day-time and performance all the time, compared to younger subjects when on a simulated 12-hour shift schedule. The investigation of the irregular schedules used by the Australian Rail Industry train driver suggested that this schedule may lead to serious reductions in sleep. The drivers do not adapt their sleep wake patterns to their schedule. When this is combined with break durations between consecutive shifts as short as 8-hours, drivers are often having inadequate sleep between shifts. It is also clear that the amount of sleep accumulated between consecutive shifts depends not only on the duration of the break but also when that break is taken during the 24 hour day.

Future Directions

In the future it may be useful to expand the research presented in chapter two, to equate the influence on performance of the partial sleep deprivation commonly reported in shiftworkers as a blood alcohol equivalent. This could be done in several ways; by simulating the sleep disruption associated with shiftwork in the laboratory or by restricting sleep. While the study presented in chapter two highlights the potential impact of sleep loss and fatigue it does not do so in a way that can be easily translated into an industry setting. By using different tests and different experimental protocols it may prove possible to equate the performance impairment under these conditions with an equivalent blood alcohol impairment. It may also be useful to use a similar paradigm to the one reported here but rather than measure neuro-behavioural performance using standard laboratory testing, equate the performance impairment using a driving or flight simulator. Preliminary of work in this area has recently been reported by Arnedt *et al.* (1998) using a driving simulator and the results are similar to those reported in the current study.

The implications of this type of research as a tool to increase awareness of the public and policy makers of the dangers of fatigue are immense. If worker fatigue is managed in a similar way to worker alcohol consumption it may reduce the risks associated with shiftwork. However, industry is primarily concerned with profit. Any strategies to try and reduce worker fatigue are always constrained by what industry and the worker will tolerate.

While it is important to be able to provide an easily grasped index of the relative impairment associated with sustained wakefulness it is also important to be able to accurately and reliably determine the impact of shiftwork on workers in a variety of shiftwork settings. This may also make it easier to manage shift schedules more appropriately. Furthermore, if as researchers we have a better understanding of the effects of shiftwork on sleep and performance we are better able to target specific areas of need. For example is it better to reduce fatigue by manipulating schedules or would it be more appropriate to spend time on technologies that reduced fatigue, shift rhythms, alert shiftworkers or help them cope with the impact of psycho-social factors?

In the quest for information on the influence of shiftwork on sleep, things such as the development of algorithms for the measuring of sleep-wake behaviour with instruments such as wrist actigraphy may enable us to objectively determine the influence of schedules on sleep without significant interference to the subjects lifestyle. Ultimately it would be useful to measure sleep-wake activity with both electrophysiological and actigraphic measures simultaneously. This would allow a comparison of EEG and actigraphy in a real world setting, to determine the influence of environmental factors on the correlation between these measures.

Another important aspect of determining the impact of shiftwork, is not to generalise findings from young healthy subjects to other groups, for example older shiftworkers or those with children. The results of the current study suggest that age is an important factor in determining adaptation to shiftwork. With the increasing number of older shiftworkers in the workforce in Australia and the United States (Australian Bureau of Statistics, 1993; 1997; NIOSH, 1998) it is important to more clearly determine the impact of shiftwork and associated sleep loss on performance of older compared to younger subjects. Further more it would be important to determine whether the impairment reported for laboratory type tasks, translates into impairment on 'real work' tasks and whether experience results in individuals being able to maintain performance for longer periods as is suggested by Gillberg *et al.* (1996).

In an attempt to look more closely at the effects of shiftwork on the worker in a real world setting this series of field-based studies were carried out. The protocol outlined in chapters six and seven is a valid and reliable method of determining the impact of shift schedules on the sleep, performance and circadian adaptation of train drivers. There is no reason to think that this type of study could not be implemented in other industries. In fact there are numerous studies in the literature that utilize similar techniques to investigate the impact of work schedules in many sectors of the transportation industry including rail, air crew and trucking (Milter *et al.*, 1997; Heitemann *et al.*, 1997; Barnes *et al.*, 1997). This type of protocol could be used to monitor any changes to a roster schedule. For example it may be necessary to identify the ability of shiftworkers to cope with changes to the roster due to changes in work load. Within the rail industry the same number of drivers are used to cover busy periods like harvest time, when grain needs to be transported quickly. In addition, during peak holiday season the pressure for airline pilots and air traffic controllers may be increased due to an increase in the number of flights available at these times. All of these types of changes in scheduling could be investigated and monitored quite quickly and easily for different industries. Another use of this type of study could be to determine the impact of education and training for shiftworkers, to determine whether the education given has any measurable impact on the behaviour of shiftworkers.

This type of study provides a wealth of information for researchers about the influence of shiftwork on workers. It may even be possible to identify individual factors that make it easier for some workers to cope with shiftwork better than others. Further analysis of the large database collected from the railways project could for example examine the influence of specific shifts and work loads on sleep and performance in these drivers. This may in turn provide a better understanding of some of the differences that are seen in the level of adaptation and impairment for different schedules.

Ultimately the aim of this type of industry based research is to be able to provide the industry with accurate information about how best to reduce the risk of accidents, performance impairment and to increase productivity and efficiency of their workers

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