FIELD STUDIES OF SLEEP AND PERFORMANCE IN OPERATIONAL SETTINGS

By

JENNIFER LYNN MCDONALD

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of JENNIFER LYNN MCDONALD find it satisfactory and recommend that it be accepted.

Paul Kwon, Ph.D., Chair

Gregory Belenky, M.D.

Dennis Dyck, Ph.D.

JP Garofalo, Ph.D.

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FIELD STUDIES OF SLEEP AND PERFORMANCE IN OPERATIONAL SETTINGS

Abstract

by Jennifer Lynn McDonald, Ph.D.
Washington State University
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Chair: Paul Kwon

Sleep loss leads to degraded alertness and cognitive performance. The management of factors influencing performance (time on task, sleep/wake history, and circadian rhythm) is important to workplace effectiveness. Contemporary work schedules limit sleep opportunities, leading to chronic sleep restriction. The present studies sought to examine the relationship between extended work hours, sleep, and subsequent performance.

In Study 1, equipment maintenance personnel were studied during normal and extended work hours. Objective measures of sleep and performance demonstrated that extending work hours was associated with sleep loss. In this study, for each additional hour worked, an hour of sleep was lost. Contrary to expectations, objectively measured performance improved in the extended work hours condition.

In Study 2, medical residents were studied while working both day shifts and a one month "night float" (extended night shift) rotation. In addition to the sleep and performance measures obtained in Study 1, two measures of learning and memory performance were administered. Medical residents obtained nearly equal amounts of objectively measured sleep while working both day and night float shifts; however, how this sleep was obtained differed between the day shift and night float conditions. Day shift sleep was obtained in a single, off shift, night time sleep bout. For the night float, some sleep was obtained in an off shift, daytime

sleep bout. This daytime sleep bout was supplemented in the night float condition by napping on shift, while working the night float. By thus augmenting their truncated daytime sleep with night time, on shift naps, residents obtained near equivalent amounts of total sleep/24 hours working day shift and night float. Consistent with equivalent total sleep times between conditions, no differences in objective performance working day shift or night float were found.

Field studies such as the ones presented here will be instrumental to forming the evidence-base of a fatigue risk management system. Such a system would allow for the management of sleep and duty times to sustain optimal performance in the workplace.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEDICATION

For Kellen.

CHAPTER ONE

OVERALL INTRODUCTION

Sleep, Circadian Rhythm, and Performance

Sleep loss (sleep deprivation and sleep restriction) leads to fatigue, operationally defined as degraded alertness and cognitive performance. Sleep-loss related fatigue is largely a function of three components: sleep/wake history, circadian rhythm, and workload (Bonnet, 2005; Dinges & Kribbs, 1991; Dinges, Rogers, & Baynard, 2005; Wesensten, Belenky, Thorne, Kautz, & Balkin, 2004). Sleep loss degrades subsequent performance over time (Pilcher & Huffcutt, 1996). Performance naturally varies over the 24-hour period of a day, parallel to circadian changes in temperature (Van Dongen & Dinges, 2005). Disruption of circadian rhythms through changes in light exposure relative to normal sleep periods (e.g. working night shifts, travel across time zones) impairs alertness and performance (Akerstedt, Peters, Anund, & Kecklund, 2005; Folkard, Lombardi, & Tucker, 2005). Workload, in addition to shift timing and duration, contributes to performance degradation by increasing time on task effects and decreasing sleep opportunity (Wesensten, Belenky, & Balkin, 2005).

Laboratory studies have demonstrated that both acute, total sleep deprivation and chronic, partial sleep restriction lead to decrements in alertness and cognitive performance, well-being, and health. Mild, moderate, and severe sleep restriction (7, 5, or 3 hours time in bed/night for 7 days) led to sleep-dose-dependent decreases in performance over time relative to baseline and in comparison to mild sleep augmentation (9 hours time in bed/night) (Belenky et al., 2003). For the 7 and 5 hour time in bed per night groups, performance appeared to stabilize at lower levels after 3-4 days while for the 3 hour time in bed per night group performance continued to degrade across the 7 day experimental period. In a parallel study, chronic sleep restriction of 6 and 4 hours time in bed per night for 14 days led to cognitive decrements comparable to 1-2 days of total sleep deprivation (Van Dongen et al., 2003). In these seminal sleep restriction studies (Belenky et al., 2003; Van Dongen et al., 2003), sleep restriction degraded performance in a sleep-dose-dependent manner. Even mild sleep restriction degraded performance over time (Belenky et al., 2003).

The circadian rhythm (the 24 hour rhythm of the endogenous biological clock) modulates alertness, performance, and sleep propensity (Achermann & Borbély, 1994; Borbély & Achermann, 1999; Dijk & Czeisler, 1995). The circadian rhythms in both sleep propensity and performance parallel the circadian rhythm in core body temperature. It is difficult to fall asleep and to stay asleep when core body temperature is rising or high; it is easy to fall asleep and to stay asleep when core body temperature is falling or low. With respect to circadian rhythm effects on performance, studies have shown that the circadian rhythm modulates performance. Performance reaches its peak following the peak in the circadian temperature rhythm and reaches its trough following the trough in circadian temperature rhythm. Thus, in addition to sleep/wake history, the circadian rhythm has been found to modulate alertness, sleep propensity, and performance.

Workload is not well defined and hence not easily measured in either laboratory or field. Fatigue as a result of time on task has been shown to be relieved by breaks within shift. Thus, fatigue from time on task recovers in part after a simple break from the task and does not require sleep. In contrast, fatigue and performance decrements related to time awake cannot be reversed without sleep (Dawson & McCulloch, 2005). Overall, the fatigue resulting from working long hours or overtime shifts increases the risk of accident (Dembe, Erickson, Delbos, & Banks, 2005). Thus, fatigue increases with increasing time awake, shift length, and time on task.

Time of day modulates the effect of workload. Risk of injury, a metric of decreased performance, varies across different shifts, with the lowest rates of injury risk on morning shifts and highest rates on night shifts (Folkard & Tucker, 2003). Furthermore, as expected due to circadian phase, injury rates on the job have been shown to be highest during the natural late night/early morning circadian low (Folkard & Tucker, 2003). As described earlier, even mild to moderate sleep loss, common for night shift workers who typically experience restricted sleep during the day (Akerstedt, 2003), leads to decrements in performance (Belenky et al. 2003). Workload, time of day, and sleep loss all interact to affect subsequent performance.

The Operational Environment

The operational environment is defined as an environment in which human performance plays a critical role and there is a high risk that if the human fails to perform, the system will fail. The human in the operational loop has limited time to decide and act upon a course of action in the operational setting (Wesensten, Belenky, & Balkin, 2005). Operational environments include military units and maritime operations, medicine, transportation, aviation, security work, and industrial production. In these settings, operational demands described previously (i.e., shift timing and duration; work intensity; and the difficulty and complexity of the work) degrade performance directly through the effects of workload and indirectly by reducing the amount of time available for sleep and thus TST, a primary determinant of alertness and performance (Wesensten, Belenky, & Balkin, 2005).

Degraded operational performance leads to loss in productivity and decrease in safety through increased risk of error, incident, and accident. Human failure, with sleep loss as a contributing factor, resulted in several major industrial accidents, including Chernobyl, Three Mile Island, and the Exxon Valdez (Folkard & Tucker, 2003). Risk of accident on shift increases approximately 18% on afternoon shifts and 30% on night shifts compared to the risk on the morning shift, with risk increasing across successive nights worked (Folkard & Tucker, 2003). A significant increase in injury rates results from degraded operational performance (Brogmus & Maynard, 2006). This risk extends past the actual shift worked. Rate of motor vehicle accidents following night shift work is greater than that following day shift work (Gabarino et al. 2002; Barger et al., 2005; Owens, 2007).

Measuring Sleep and Performance in the Operational Environment

Sleep can be measured objectively, using polysomnography and actigraphy. Polysomnography (PSG) is the standard of sleep measurement in laboratory studies of sleep and performance. PSG measures the electrical potentials of the brain, eyes, and muscles, as well as heart and respiration rates, through a network of electrodes attached to the subject's scalp and body. These measures allow for scoring of sleep stage (e.g., rapid eye movement or non-rapid eye movement sleep) as well as the stages of non-rapid eye movement sleep (Ancoli-Israel, 2005; Carskadon & Rechtschaffen, 2005). Actigraphy is useful and reliable as a measure of total sleep time (TST) and is validated against PSG (Ancoli-Israel, Cole, Alessi, Chambers, Moorcraft & Pollak, 2003; Ancoli-Israel, 2005). Actigraphy is useful for measuring TST, the primary sleep-related determinant of performance, in field studies where PSG is not feasible (Ancoli-Israel et al., 2003; Ancoli-Israel, 2005). Actigraphy uses a small, wrist-watch like device that records movement (determined by an internal accelerometer and recorded in 60-second epochs) which provides an activity record from which sleep/wake history and TST/24 hours can be scored. This method can be used to collect continuous sleep/wake history data over 24-hour periods for weeks at a time and allows for collection of an objective measure of TST comparable to that obtained by PSG in a laboratory study (Ancoli-Israel et al., 2003; Ancoli-Israel, 2005).

Thus, reliable and accurate measures of TST, a determining factor for subsequent performance, can be obtained in naturalistic operational settings over long periods of time through non-intrusive means.

Alertness and cognitive performance (attention, vigilance, and learning/memory) can be measured in the laboratory by computer-based test batteries and in the field by self-report and by laboratory tests ported to personal digital assistants (PDAs) and other similar devices or by direct administration (paper and pencil testing). Alertness, attention, and vigilance can be measured in field studies through use of a psychomotor vigilance task (PVT) (Dinges & Powell, 1985). The PDA-based PVT is a portable reaction time task that measures the ability to sustain attention and vigilance over time. Sustained attention may be reflected in various metrics, including mean reaction time (RT) in milliseconds, the reciprocal of reaction time (1/RT), mean fastest 10% RT, mean slowest 10% RT, and lapses (RTs > 500ms), referred to as the "slowest RTs of all" (Graw, Krauchi, Knoblauch, Wirz-Justice, & Cajochen, 2004). Reaction time on the PVT is sensitive to time of day (circadian rhythm) and sleep loss (Blatter et al., 2006; Pilcher & Huffcutt, 1996; Wesensten et al., 2004). Chronic sleep restriction, 4-6 hours of TST per 24 hours for 14 days, leads to decreases in performance comparable to experiencing 1-2 days of total sleep deprivation (Van Dongen et al., 2003). Even mild to moderate sleep restriction (7 and 5 hours time in bed, respectively) leads to performance degradation (Belenky et al., 2003). The ability to sustain attention and to maintain alertness and vigilance is important to successful operations and effectiveness in most work settings.

Impact of Total Sleep Time on Performance

Performance depends primarily on TST (main sleep bout plus naps) in 24 hours and not on the distribution of sleep stages (e.g. rapid eye movement and non-rapid eye movement).

Thus, TST measured by actigraphy can be used to predict performance in operational settings (Ancoli-Israel, 2005; Wesensten, Balkin, & Belenky, 1999). Night shift workers who sleep during the day, even if they have a consolidated 8 hours available for sleep, are unable to sleep more than about 5 hours because they are attempting sleep at an adverse circadian phase (Akerstedt, 1998). This sleeping out of circadian phase results in a state of chronic, partial sleep restriction and leads to subsequent performance decrements. Split sleep, sleeping in more than one bout in 24 hours, sustains performance as well as the same amount of consolidated sleep (Belenky et al., 2008; Mollicone, Van Dongen, and Dinges, 2007; Mollicone, Van Dongen, Rogers, and Dinges, 2008). For night shift workers, splitting sleep and thereby placing at least some of the sleep opportunity at a more sleep-conducive circadian phase will increase TST and thus help sustain alertness and performance. Napping is a potential way to maintain TST and improve performance in shift workers whose main sleep period occurs at an adverse circadian phase.

Napping, when the main sleep period is restricted or absent, improves performance (Akerstedt, Kecklund, & Gillberg, 2007; Dhand & Sohal, 2006; Dinges et al., 1987; Dinges et al., 1988; Gillberg et al., 1996; Haslam, 1985; Hartley, 1974; Hayashi, Fukushima, & Hori, 2003; Horne & Reyner, 1996; Mullaney, Kripke, & Fleck, 1983; Nicholson et al., 1985; Pilcher et al., 2005; Reyner & Horne, 1997; Rosekind et al., 1995; Takahashi & Arito, 2000; Waterhouse, Atkinson, Edwards, & Reilly, 2007). Napping may be the most effective way to counter fatigue, improving performance by increasing TST (Akerstedt, 2003). Recent studies have demonstrated that TST is unaffected by whether the sleep opportunity is split or consolidated (Mollicone, Van Dongen, & Dinges, 2007). Furthermore, follow-on work indicates that performance is a function of TST, regardless of whether the sleep is consolidated or split

(Mollicone, Van Dongen, et al., 2008). These studies examined main sleep bout at night and napping during the day. A study reversing that order is currently being conducted.

In short, it does not matter whether sleep is obtained all in a single sleep bout or distributed in 2 or 3 bouts over 24 hours. TST per 24 hours, including both main sleep period and napping, is the key to performance.

Summary of Sleep and Performance Issues in Operational Settings

Although the effects of sleep loss on performance are well documented in laboratory studies (Belenky et al., 2003; Van Dongen et al., 2003), there are few field studies or objectively measured data demonstrating the effects of chronic partial sleep restriction on individuals in their work environments over weeks of time while they are simultaneously meeting their occupational, family, and community responsibilities. As such, we have limited practical understanding of how sleep/wake history, circadian rhythm, and workload interact to influence productivity in the workplace. Objectively measured data on sleep and performance in operational settings will be useful to improve workplace productivity and worker health and safety. Such data would be useful in developing and validating mathematical models that predict performance based on sleep/wake history and circadian rhythm. Validated models predicting performance from sleep/wake history could form the basis of an evidence-based fatigue risk management system with the potential to improve productivity and reduce the risk of error, incident, and accident in operational settings.

Present Studies

The current literature in sleep and operational performance demonstrates a need for further research and forms the basis of two main hypotheses for these studies:

1) With extended work hours, sleep opportunity and thus, total sleep time, will be reduced, impairing subsequent performance (attention and vigilance).

2) With night shift work, sleep opportunity will be adequate in length but not optimum in circadian placement, thus reducing actual sleep time and subsequent performance (attention, vigilance, and learning/memory).

While anecdotal evidence is available for these hypotheses, objective data is limited. There are only two well-controlled laboratory studies in which the alertness and performance effects of more than five consecutive days of sleep restriction have been studied (Belenky et al., 2003; Van Dongen et al., 2003). There are few published naturalistic field studies that assess daily total sleep time in persons in modern occupations/careers as they meet their occupational, family, and community responsibilities over a week or more. There are only two field studies in which the effects of the variations in total sleep time on performance across a week or more (e.g. extended sleep on days off/weekends vs. workdays/weekdays) have been assessed using objective measures (Landrigan et al., 2004; Lockley et al., 2004).

Given these hypotheses and the lack of objective data in naturalistic field studies, the present studies sought to:

1) Determine whether working extended work hours lead to reduced total sleep time/24 hours in biopharmaceutical industry employees, therefore resulting in decreased objective performance as compared to normal work hours.

2) Determine whether working extended night shifts lead to reduced total sleep time/24 hours in medical residents, therefore resulting in decreased objective performance as compared to day shift work. A second component sought to determine whether learning and memory are adversely affected by working extended night shift hours.

CHAPTER TWO

STUDY 1 INTRODUCTION

As discussed in Chapter One, sleep-loss related fatigue is a function of three interrelated components: sleep/wake history, circadian rhythm, and workload (Bonnet, 2005; Dinges & Kribbs, 1991; Dinges, Rogers, & Baynard, 2005; Wesensten et al., 2004). Sleep-loss related fatigue leads to decreased efficiency and productivity in the workplace, increased accidents, and additional costs to both employers and employees (Folkard, Lombardi, & Tucker, 2005). Furthermore, sleep loss is associated with significant mental and physical health consequences, such as overweight and obesity (Knutson, Spiegel, Penev, & Van Cauter, 2007; Spiegel, Leproult, & Van Cauter, 1999; Spiegel, Knuston, Leproult, Tasali, & Van Cauter, 2005), hypertension (Meier-Ewert et al., 2004) and cardiovascular problems (Harma, 2006; Knutsson, 2003), gastrointestinal disease (Costa, 1996; Gabarino et al., 2002), chronic fatigue, substance/alcohol abuse, family problems, and mood difficulties (Costa et al., 2004; Hirose, 2005; Papp, Miller, & Strohl, 2006; Whitehead, Thomas & Stapper, 1992). The evidence for negative effects of sleep-loss related fatigue is varied and far-reaching.

Total sleep deprivation greater than 24 hours is rare in workplace environments; partial chronic sleep restriction is much more common. The effects of total sleep deprivation are well studied; however, there are only a handful of laboratory studies examining the effects of chronic sleep restriction (Balkin et al., 2000; Belenky et al., 2003; Carskadon & Dement, 1979; Van Dongen et al., 2003). There is currently limited data on the effects of chronic sleep restriction on individuals in their work settings over weeks and months. Understanding how sleep/wake history, circadian rhythm, and workload influence sleep-loss related fatigue in the workplace is important to sustaining workplace effectiveness, as well as to the mental and physical well-being of employees.

Many studies have been conducted to examine the effects of work hours on worker safety and the safety of the general public. This research has been used to develop public policy, with a recent focus supporting the development of fatigue risk management systems to be employed within or as an alternative to prescriptive rules. The majority of these studies have focused on the relationship between work hours and performance rather than the relationship between sleep and performance. The performance measures used fall into three general categories: added metrics (those not intrinsic to the workplace, such as laboratory tests like the PVT described in Chapter One), embedded metrics (those intrinsic to the workplace, such as lane deviation in trucking), and performance metrics drawn from simulators. In the studies that demonstrate a link between longer work hours and degraded performance this link is presumably mediated by a combination of sleep loss, circadian rhythm phase, and time on task (or workload).

Much research has been conducted with medical professionals and the commercial trucking and railroad industries, with the intent of the study being relevance to public policy and safety. Research with other shift workers has focused mainly on schedule optimization and safety, concentrating on measurements of hours worked and hours slept. Research with a third population of interest, workers who work extended work hours, either by virtue of working extended hours in a single shift or by working multiple shifts in a 24-hour period (e.g. working a double shift or holding two jobs) has been relatively sparse, with a couple of exceptions (refs).

The present study sought to examine the relationship between extended work hours, sleep, and subsequent performance. Data from 10 equipment maintenance personnel (all male) employed in a biopharmaceutical production facility were used to determine whether working extended work hours (for a 9 day period) resulted in decreased total sleep time/24 hours and decreased performance compared to a period of normal work hours (for a 10 day period). We hypothesized that extending work hours would lead to reduced opportunity for sleep, therefore resulting in reduced overall total sleep time/24 hours and decreased subsequent objective performance.

CHAPTER THREE

STUDY 1 RESEARCH DESIGN AND METHODOLOGY

Participants

Ten volunteers were recruited over a two-month period (June-July 2007) from equipment maintenance personnel at a biopharmaceutical production facility. Data collection took place from August 2007-September 2007. Volunteers were included if they: 1) came from the target population; 2) were fit to work by target population standards; 3) were working in the workplace; and 4) wished to participate and gives informed consent. Volunteers were excluded if they did not meet these four criteria. Typically, these personnel (both production and supervisory) work normal 8-hour day shifts and 40-hour work weeks punctuated by periods during which, for several days, work hours are extended from the normal 8-hours/day to 13-14 hours/day. These several day periods of extended work are predictable. In the control portion of this study, volunteers were studied for ten days while working normal 8-hour days, either just before or two weeks after a period of extended work hours. Volunteers were studied for a period of nine days during extended work hours. No formal experimental schedule manipulation was required. These normal and extended work hour schedules were normally occurring.

Written and informed consent was obtained from all volunteers. Protocol approval was obtained from the Institutional Review Board (IRB) at Washington State University (WSU) and the Human Research Protection Office (HRPO) of the United States Army Medical Research and Materiel Command (USAMRMC) Office of Research Protections (ORP). The study was supported by USAMRMC award W81XWH-05-1-0099.

The total sample of volunteers included 10 male employees (mean age 42.2 years; range 25-53 years). All participants completed the study. Each volunteer served as his own control.

Measures

Actigraphy (Ancoli-Israel, 2005; Ancoli-Israel, Cole, Alessi, Chambers, Moorcraft & Pollak, 2003): Volunteers wore a sleep watch/actigraph continuously over the course of the study. The actigraphs utilized in this study came from Ambulatory Monitoring, Inc., Ardsley, New York. The actigraph (a wrist-worn, wrist-watch size device) uses an accelerometer to detect arm movements and records these as activity counts per minute across successive one-minute epochs. Using a validated, automated, computer-algorithm (Sadeh, Alster, Urbach, & Lavie, 1989), the activity record is scored to determine whether for any given minute, the volunteer is asleep or awake. This yielded a continuous minute-by-minute sleep/wake history over the course of the study, thus providing a consistent measure of objective sleep from record to record, participant to participant

Psychomotor Vigilance Task (Dinges & Powell, 1985): As described in Chapter One, the Psychomotor Vigilance Task (PVT) is a 10-minute, Palm OS personal data assistant (PDA) based, portable reaction time task that measures the ability to sustain attention and vigilance over time. Volunteers completed this task at shift-onset and shift-end for the duration of the study.

Daily Work and Sleep Log: Volunteers maintained a daily log of main daily sleep period start and end times for each day of the study, as well as shift start and end times on days worked during the study.

Procedures

Volunteers completed a written informed consent, as well as a 20-minute paper and pencil survey eliciting demographic data, height and weight, average daily caffeine consumption, and information on health and well-being.

Volunteers wore an actigraph continuously during the course of the study to measure sleep/wake history. They also completed a 10-minute, PDA-based PVT at the beginning and end of each shift during the study. They also completed a daily work and sleep log, recording main daily sleep period start and end times and shift start and end times for the duration of the study.

CHAPTER FOUR

STUDY 1 RESULTS

Statistical Analyses

Because of the within-subjects design of the studies, mixed-effects ANOVA was chosen to analyze the data (Van Dongen et al., 2004). Mixed-effects ANOVA offers the ability to determine whether differences between means induced by the experimental manipulation (fixed effects) are significant relative to the error variance, just as is possible with repeated-measures ANOVA. However, with mixed-effects ANOVA, between-subjects variance attributable to systematic individual differences (random effects) is dissociated from the error variance (within-subjects variance), thereby reducing the magnitude of the error variance that is used in the evaluation of the differences between means. This is important in research on sleep and performance due to the considerable trait individual differences in sensitivity to sleep loss (Van Dongen et al., 2005).

There are several other advantages to using mixed-effects ANOVA rather than repeated-measures ANOVA (Gueorguieva & Krystal, 2004). Mixed-effects ANOVA makes use of all available data and is not adversely affected by randomly missing data, such as data lost to equipment failure. With mixed-effects ANOVA, if subjects are missing data, they need not be excluded from analysis. This is important to field study work with limited numbers of participants and reduced experimental control compared to laboratory studies. Further, mixed-effects ANOVA allows evaluation of individual differences expressed systematically over time or across conditions.

Primary Outcome Measures

Statistical analyses for study 1 were conducted using data from 10 male volunteers (mean age: 42.2 years; range 25-53 years). All participants completed all parts of the study and each served as his own control. Consistent with our hypothesis, a mixed-effects ANOVA for shift duration revealed that employees worked approximately 1.2 hours more per day during extended work hours (EWH) (10.3 ± 0.3 hours) than during normal work hours (NWH) (9.1 ± 0.2 hours) ($F[1,119] = 20.2$, $p < 0.01$) (see table 1). Also consistent with our hypothesis, mixed-effects ANOVA revealed that employees slept approximately 0.9 hours less per night while working EWH (6.0 ± 0.2 hours) than they did while working NWH (6.9 ± 0.2 hours) ($F[1,119] = 28.5$, $p < 0.01$) (see table 1).

Contrary to hypotheses, mean PVT RT, an objective measure of performance, was faster during EWH (303 ± 13 ms) than during NWH (326 ± 13 ms) ($F[1,243] = 17.3$, $p < 0.01$) (see table 2). Mean PVT RT performance was not significantly different between shift onset (317±13ms) and shift end (311 ± 13ms) ($F[1,243] = 1.18$, $p = 0.28$); interaction with condition and shift: $F[1,243] = 0.02$, $p = 0.89$). PVT administration at shift onset and shift end occurred on average at 09:04 and 17:19 during NWH, and at 06:20 and 15:48 during EWH.

Secondary Outcome Measures

In agreement with results for mean PVT RT, lapses during PVT performance (defined as reaction times $\geq$ 500 ms) were more frequent during NWH (4.9 ± 0.9) than during EWH (2.2 ± 0.9) ($F[1,243] = 23.9$, $p < 0.01$) (see table 2). Lapses did not differ significantly between shift onset (3.7 ± 0.9) and shift end (3.5 ± 0.9) ($F[1,243] = 0.21$, $p = 0.65$; interaction with condition and shift: $F[1,243] = 0.46$, $p = 0.50$).

CHAPTER FIVE

STUDY 1 DISCUSSION

Extending work hours limits sleep opportunity and restricts total sleep time, leading to chronic partial sleep restriction (Dawson & McCulloch, 2005). In the present Study 1, for every additional hour worked, a nearly equivalent amount of sleep was lost (see table 1). Thus, Study 1 provides objective evidence in a field study of the effects of working extended work hours on sleep and performance.

Though actual sleep was decreased while working by extended hours, this study found no evidence of detrimental effects on objectively measured performance (see table 2). In fact, contrary to expectations, mean PVT RT performance was faster during the extended work hours period than it was during normal work hours period. One explanation for this is the obvious: this amount of mild sleep restriction does not impair performance. However, it should be noted that it was not possible to counterbalance conditions, as these were naturally occurring shifts with individuals serving as their own controls. Additionally, PVT performance is modulated by circadian rhythm (Van Dongen & Dinges, 2005). There were definite differences between conditions in the circadian timing of PVT test bouts due to differences in shift start and end times. It could be that mean PVT RT performance did not actually improve, but was enhanced by the circadian timing of the testing bouts at shift start and end time in the extended work hours condition.

Additionally, the study may not have been long enough to detect the effects of the mild sleep restriction resulting from working extended hours. While laboratory studies have demonstrated the effects of sleep restriction after just five days (Belenky et al. 2003; Van Dongen et al., 2003), it is possible that other factors in the operational setting affect the rate at which those decrements emerge (e.g., dietary intake, caffeine use, and substance use), none of which were controlled for in this study.

A third explanation for this performance finding is that the PVT may be more complex than is commonly thought (e.g. as a simple reaction time task reflecting basic cognitive processes). The PVT may reflect the more effortful and complex mental processes of concentration and of sustained, willed action. Social psychologists have proposed a model of self-regulation relying upon a limited resource of executive function, subjectively termed willpower or self control (Schmeichel & Baumeister, 2004). According to this model, an individual has the ability to exercise self control in one task, but performance on a subsequent task, following the prior exertion of self control, is diminished due to "ego depletion," manifested as mental fatigue (Baumeister & Vohs, 2003). Individuals are able to exert sustained attention and self control over time, if the reinforcement for doing so is high; however, their performance on longer-duration activities requiring attention and self control decreases substantially even in the presence of reward (Baumeister & Vohs, 2003).

Baumeister & Vohs (2003) do not specify a time frame for longer-duration activities. The facility in which this study was conducted undergoes an annual equipment tear down and rebuild phase of approximately two weeks, during which personnel work extended hours. It is a period of intense work with significant consequences for failure to perform well. This study was conducted during this rebuild period. Perhaps in this study, the rewards for sustained attention, or conversely, the consequences for failure, were sufficient over this short time period for personnel to manage their performance outcomes despite mild sleep restriction.

Study 1 utilized a small, tightly knit sample of volunteers. It may be the case that with a larger, less tightly knit sample, a different outcome may result. Regardless, the study provides objective evidence in a naturalistic setting that extended work hours limit subsequent sleep time.

Current field studies of sleep and performance generally lack a consistent, standardized objective methodology and frequently do not include objective measures of sleep. Additionally, these studies focus on varying aspects of fatigue in the workplace (e.g. time awake, performance, number of hours worked). It should be remembered that total sleep time is the main primary factor determining subsequent performance. When total sleep time is restricted, for example, by extending work hours, objectively measured performance will likely, contrary to the findings in the present study, degrade over time.

This study is one of a few that objectively measured sleep *and* performance in the field environment. Field studies of sleep and performance provide an evidence base for managing fatigue-related risk in the workplace. This study demonstrates that extending work hours results in restricted total sleep time, as measured by actigraphy record using a validated, automated, computer-algorithm to score sleep. As such, it can be utilized, with other objectively measured studies, to further develop a fatigue risk management system that will allow for optimization of scheduling to ensure adequate sleep opportunities given operational constraints and to develop public policy regarding occupational health and safety.

CHAPTER SIX

STUDY 2 INTRODUCTION

In addition to the sleep-loss related fatigue discussed in Chapters One and Two, a substantial body of evidence demonstrates decreased safety due to degraded operational performance in medical settings. Medical residents work schedules similar to those of rotating shift workers and workers working extended hours, and experience similar degrees of sleep loss and subjective complaints (Epstein, Tzischinsky, Herer, & Lavie, 2001). Residents on call show decreased sleep as measured by actigraphy and decreased performance as measured by the PVT (Saxena & George, 2005). The post-call performance of residents working a heavy call rotation (averaging 90 hours on duty per week) is comparable to performance at a blood alcohol concentration of .04 or .05 g/100 ml (Arendt et al., 2005).

A study by the Harvard Work Hours, Health and Safety Group compared performance of 20 medical residents on traditional work schedules (averaging 85 hours on duty per week) with performance of the same residents working on an intervention work schedule (averaging 65 hours on duty per week) (Landrigan et al., 2004; Lockley et al., 2004). They found that medical residents slept nearly 6 hours more per week and had less than half the rate of attentional failures (as measured by electrooculography) when they worked the intervention schedule compared to the traditional work schedule (Lockley et al., 2004). Furthermore, they found a substantial decrease in non-intercepted serious medical errors (medical errors that either caused harm or had the potential to cause harm *and* reached the patient) when the residents worked the intervention schedule (100 medical errors/1000 patient-days on the intervention schedule) than when they worked the traditional schedule (136 medical errors/1000 patient-days) (Landrigan et al., 2004).

Further investigations surveying 2,737 medical residents supported and extended the above findings. These studies found that working extended hours (≥ 24 hours) compared to working a normal day shift increased automobile crashes, near misses, and falling asleep while driving (Barger et al., 2005). Working extended hours was also associated with increased medical errors, attentional failures (e.g., falling asleep during lectures, rounds, and patient care (including surgery)), and "fatigue-related adverse events resulting in fatality" (Barger et al., 2006). Finally, working extended hours was related to increased incidence rates of percutaneous needle sticks (Ayas et al., 2006). These studies (Ayas et al., 2006; Barger et al., 2005, 2006; Landrigan et al., 2004; Lockley et al., 2004) indicate a risk to physicians, patients, and the general public from the physicians working extended hours. They demonstrate that performance is impaired with extended work hours and (given the attentional failures) the ability to learn is likely impaired as well.

Learning and Memory in Medical Residents

Medical residents are a unique population - they are required to provide continuous patient care (performance) in addition to continuous learning (learning and memory) on shift. In studying medical resident performance and learning/memory, measuring alertness and attentional performance can be reliably accomplished using the PVT. Measuring learning and memory requires other tests.

A meta-analysis of 60 studies investigating cognitive performance in healthcare professionals supports the hypothesis that cognitive performance decreases with sleep loss; however, definitions of cognitive performance and sleep varied significantly (Philibert, 2005). Many tests have been utilized with medical residents to determine what the impact of working extended hours and night shifts are on neuropsychological performance. There has been little consistency in findings from these studies. A study of 26 surgical residents on call every other night found no performance degradation as a result of sleep loss using a battery of neuropsychological tests (the Paced Auditory Serial Addition Test, the Trail Making Test, the Grammatical Reasoning Test, the Minnesota Paper Form Board Test, and the Purdue Pegboard) (Deaconson et al., 1988). Gottlieb, Peterson, Parenti, and Lofgren (1993) studied 41 residents on an overnight call system with 45 residents on a night float system designed to minimize sleep loss. They used the Wisconsin Card Sort Task, the Letter-Concentration Task, the Logical Memory Subtests of the Weschler Memory Scale-Revised, the Lafeyette Grooved Pegboard, and vocabulary and block design subtests from the Weschler Adult Intellignce Scales to measure cognitive functioning and also found no significant effect of sleep loss on test performance. These researchers proposed that the additional attention and concentration required during testing may mask the effects of sleep loss on more routine physician tasks. Significant results showing test score decreases were found, however, in a study of 30 medical residents using two other neuropsychological measures (the California Verbal Learning Test II and the Grooved Pegboard test) (Halbach, Spann, & Egan, 2003). Again, these researchers stated the results of these tests may not be representative of real world performance.

Visual vigilance and complex tasks appear to be more vulnerable to sleep loss than other functions. Robbins & Gottlieb (1990) performed a study of 23 house staff in which they found decreases on three out of four visual and complex tasks (a simulated driving task, a Rapid Number Comprehension task, and a Concentration task); however, the lack of norms for the tests made interpretation difficult. A later study of 12 medical interns (Rollinson et al., 2003) found that visual memory capacity was decreased as measured by the Delayed Recognition Span Test between the beginning and end of a 12 hour night shift, but no other degradation was found in performance on other tests conducted (Continuous Performance Test and Santa Ana Form Board

Test). The study by Lockley et al. (2004) described earlier offers further evidence of degraded visual vigilance as a result of sleep loss. Residents working traditional schedules (averaging 85 hours on duty per week) experienced increased visual attentional failures, operationally defined as slow-rolling eye movement intrusion into PSG confirmed wake periods. These attentional failures were significantly decreased when an intervention schedule, increasing resident sleep by approximately 6 hours per week, was implemented.

Neuropsychological testing assessing the more global knowledge and performance, as measured by intelligence tests, has yielded more consistent findings. Assessing 16 medical residents, Dula, Dula, Hamrick, and Wood (2001) found that day shift scores after 5 consecutive day shifts on an intelligence test (the Kauffman Adolescent and Adult Intelligence Test) were significantly higher than scores obtained after 5 consecutive night shifts. This is consistent with findings from a 1990 study (Jacques, Lynch, & Samkoff) in which the effect of one night's sleep loss on test scores was equivalent to the change between the first and third years of training for the medical residents.

The findings from studies investigating learning and memory in medical residents yield conflicting results and fail to clarify what aspects of performance they are measuring. Additionally, of the studies cited above, only one obtained objective measures of sleep loss (measured through continuous PSG; Lockley et al., 2004). Two of the studies (Dula et al., 2001; Gottlieb et al., 1993) did not obtain any measure of sleep, not even self-report. The remaining studies relied on self-reported sleep hours, which are unreliable. Additionally, just one of the studies reviewed by Philibert (2005) assessed the effects of chronic partial sleep deprivation (Hawkins, Vichick, Silsby, Kruzich, & Butler, 1985), a much more common aspect of sleep loss in shift work settings such as those worked by medical residents.

The real life tasks required for patient care are very different from the continual learning and memorization necessary for medical residents to pass exams and meet educational goals.. To date, there is little literature examining how well medical residents are able to learn and retain new knowledge while working extended hours and/or night shifts compared to working day shifts.

There is also little consensus regarding the neuropsychological impact of sleep loss in medical residents while they are both performing their job duties and continuing their medical education. The majority of studies that have been conducted do not contain objective measures of sleep and/or have failed to clarify the specific aspects of performance being measured. It would be useful to broaden this work to determine the effect on learning and memory of extended work hours and night shift work in medical residents.

The present study sought to examine the relationship between working extended night shift hours, sleep time, and subsequent performance, both as measured by the PVT and by learning and memory measures. Data from 17 medical residents (13 males; 4 females) in their first and second years of post-graduate residency (PGY1 and PGY2) were used to determine whether working extended night shift hours resulted in decreased total sleep time/24 hours and decreased performance (attention, vigilance, learning/memory) compared to a period of normal work hours. We hypothesized that as compared to normal day shift work extended night shift work hours would lead to reduced overall total sleep time/24 hours and decreased subsequent objective performance.

CHAPTER SEVEN

STUDY 2 RESEARCH DESIGN AND METHODOLOGY

Participants

19 volunteers were recruited from a population of physicians in post-graduate education (medical residents) at two hospitals over a two month time period (June-July 2007). Volunteer inclusion criteria for this study were the same as for study 1. Data collection took place between August 2007 and February 2008.

Medical residents at these hospitals typically worked day shifts from approximately 07:00-18:00 daily, with a one month "night float" rotation at a scheduled time. Night float is an extended night shift (typically from 17:30 until 07:00), usually with some opportunity for sleep on shift. Both types of shifts were scheduled well in advance and hence predictable. Volunteers were studied for 5-6 days during the last week of day shift prior to starting night float, for 6-8 days during the first week of night float, for 6-8 days during the last week of night float, and for 5-6 days during the first week of day shift immediately following night float work. No experimental schedule manipulation was required. These were normally occurring schedules.

As in study 1, written informed consent was obtained from all volunteers. Protocol approval was obtained from the IRB at WSU and the Human Research Protection Office (HRPO) of the United States Army Medical Research and Materiel Command (USAMRMC) Office of Research Protections (ORP). The study was supported by USAMRMC award W81XWH-05-1-0099.

Of the 19 recruited volunteers, one volunteer dropped out of the study for personal reasons. Another volunteer was excluded from analysis because of noncompliance with the experimental protocol. The total sample included 17 volunteers (13 males; 4 females; mean age

30.4 years; range 26-50 years) in their first and second years of post-graduate residency (PGY1 and PGY2); all volunteers completed all portions of the study. Each volunteer served as his/her own control.

Measures

Actigraphy: Measures and procedures are identical to those described in study 1. Again, actigraphs utilized in this study came from Ambulatory Monitoring, Inc., Ardsley, New York.

Psychomotor Vigilance Task: Measures and procedures are identical to those described in study 1.

Daily Work and Sleep Log: As described previously in study 1.

Brief Visuospatial Memory Test-Revised (BVMT-R) (Benedict et al., 1996): The BVMT-R is a test of visual memory with six alternate forms that measure visual learning and memory via immediate recall, acquisition rate, delayed recall and recognition (Spreen & Strauss, 1998). Four of these alternate forms were used with this group of volunteers. Volunteers were presented with an 8 by 11 inch plate that shows six simple geometric visual designs in a 2 by 3 matrix for 10 seconds. The volunteer was then asked to reproduce the designs on a blank sheet of paper. A total of 3 trials for learning, using the same plate, were administered, and the volunteer was encouraged to improve performance on each trial. After a 25 minute delay, the volunteer was asked to reproduce the designs. A recognition task was then administered, with the volunteer being shown the 12 designs one at a time and responding "yes" if the design was on the original matrix or "no" if the design was not (Spreen & Strauss, 1998).

Rey Auditory-Verbal Learning Test (RAVLT) (Rey, 1941, 1964): The RAVLT is a test of verbal learning and memory with alternate forms that measure immediate memory span, new learning, susceptibility to interference, and recognition memory (Spreen & Strauss, 1998). Four equivalent RAVLT forms were utilized with these volunteers. The test was administered by reading aloud a list of 15 words for five consecutive trials, with a free recall test following each trial. Instructions and order of words remained the same across trials. An interference trial of 15 words was then administered with a free recall test of that trial. A delayed recall trial of the first list was then administered. After a 20 minute delay, a recall trial of the words on the first list was administered, along with a recognition trial where the volunteer had to decide if a word presented was on the original list of words or not (Spreen & Strauss, 1998).

Procedures

As in study 1, volunteers completed a written informed consent, as well as a 20-minute paper and pencil survey eliciting demographic data, height and weight, average daily caffeine consumption, and information on health and well-being.

Volunteers wore an actigraph continuously during the course of the study to measure sleep/wake history. They also completed a 10-minute, PDA-based PVT at the beginning and end of each shift during the study. Furthermore, they completed a daily work and sleep log, recording main daily sleep period start and end times and shift start and end times for the duration of the study. Shift start and end times for medical residents were verified by hospital records.

Volunteers in study 2 were also administered a battery of the two cognitive tasks measuring visual and verbal memory: the Brief Visuospatial Memory Test-Revised (BVMT-R) (Benedict, 1996) and the Rey Auditory-Verbal Learning Test (RAVLT) (Rey, 1941, 1964) four times during the study. These tasks took approximately 90 minutes to complete and were given at the end of the work week, at completion of day or night shift work (between 1500 and 1700 following a day shift; between 0700 and 0800 following a night shift). Four equivalent forms of the tests were used with the residents, one for each administration. The order of test administration was counterbalanced for all volunteers.

CHAPTER EIGHT

STUDY 2 RESULTS

Primary Outcomes

Statistical analyses for study 2 were conducted using data from 17 volunteers (13 males; 4 females; mean age 30.4 years; range 26-50 years) in their first and second years of post-graduate medical education (PGY1 and PGY2); all participants completed all portions of the study. Each volunteer served as his/her own control. A mixed-effects ANOVA for shift duration confirmed that the medical residents worked longer hours on night float (13.4 ± 0.2h per 24h) than on day shift (9.0 ± 0.2h per 24h) ($F[1,277] = 506.4$, $p < 0.01$) (see table 3). However, contrary to our hypothesis, there were no significant differences found in total sleep time as objectively measured by actigraphy records, using a validated, automated, computer-algorithm to score sleep (Sadeh, Alster, Urbach, & Lavie, 1989) between night float (6.8 ± 0.2h per 24h) and day shift (7.0 ± 0.3h per 24h) ($F[1,225] = 0.27$, $p = 0.60$) (see table 4). Table 4 illustrates that this equivalence in total sleep time was due to the fact that while residents slept significantly less off shift while working night float (3.8 ± 0.2h during the off shift) than they did while working the day shift (6.8 ± 0.2h during the off shift) ($F[1,166] = 144.9$, $p < 0.01$), residents were able to augment that restricted off shift sleep by sleeping on shift while working the night float shift (2.6 ± 0.2h per shift). Conversely, they sleep much less while working the day shift (0.1 ± 0.2h per shift) ($F[1,166) = 167.4$, $p < 0.01$) (see table 4). Figure 1 illustrates these sleep patterns for a typical resident in this study.

With respect to objectively measured performance, mean PVT RT did not differ significantly between night float (393 ± 28ms) and day shift (382 ± 28ms) ($F[1,500] = 2.81$, $p = 0.09$) (see table 5). Mean PVT RT did not differ between shift onset (382 ± 28ms) and shift end

(392 ± 28ms) ($F[1,500] = 2.35$, $p = 0.13$; interaction with shift: $F[1,500] = 0.59$; $p = 0.44$). PVT administration at shift onset and shift end occurred on average at 08:40 and 16:49 during day shift, and at 17:57 and 07:15 during night float.

In terms of objectively measured learning and memory, there were no significant differences found for learning between conditions for either the BVMT-R or the RAVLT using mixed-effects ANOVA. Learning, as measured by the BVMT-R Total Recall variable showed that residents' scores following day shift work (25.5 ± 1.1) were not significantly different than those following night float (26.6 ± 1.1) ($F[1,50] = 0.98$, $p = 0.33$) (see table 6). The same observation was found using the RAVLT. Residents' day shift scores (59.2 ± 1.6) were not significantly different from those obtained following night float work (57.7 ± 1.6) ($F[1,50] = 1.47$, $p = 0.23$) (see table 6).

Using mixed-effects ANOVA for analysis of the primary memory variable for each of the tests administered, no significant differences were found between conditions. For the BVMT-R, residents' scores on the Delayed Recall, a measure of how much information was retained following a 25 minute delay, were similar following both day shift (10.0 ± 0.3) and night float (9.5 ± 0.3) ($F[1.50] = 1.09$, $p = 0.30$) (see table 7). For the RAVLT, residents' Delayed Recall (a 20 minute delay in this case as opposed to the 25 minute delay required by the BVMT-R) was not significantly different following day shift work (12.3 ± 6.5) than following night float work (12.2 ± 6.5) ($F[1,50] = 0.10$, $p = 0.75$) (see table 7).

Secondary Outcomes

Secondary Outcomes of Sleep

Week-by-week comparisons of sleep, as measured by actigraphy using a sleep scoring algorithm, were not significantly different ($F[3,223] = 0.68$, $p = 0.56$) (see table 8).

Secondary Outcomes of PVT Performance

Objectively measured mean PVT RT performance was significantly different from week to week ($F[3,500] = 14.52$, $p < 0.01$) such that performance was slower week by week (see table 9).

Lapses during PVT performance were not found to be significantly different between conditions ($F[1,500] = 2.15$, $p = 0.14$) (see table 5), shift onset and end ($F[1,500] = 1.33$, $p = 0.25$); interaction with shift: ($F[1,500] = 0.09$, $p = 0.77$). In agreement with weekly mean PVT RT results, week-by-week comparisons of lapses demonstrated a significant difference ($F[3,500] = 12.15$, $p < 0.01$) such that lapses increased in each week (see table 9).

Secondary Outcomes of Memory Measures

Secondary measures of objectively measured memory on the BVMT and RAVLT also showed no significant differences when a mixed-effects ANOVA was performed. % Retained scores on the BVMT-R for day shift (96.5 ± 2.2) were not significantly different from those obtained following night float (92.5 ± 2.2) ($F[1,50]= 1.65$, $p = 0.20$) (see table 10). BVMT-R Recognition Index scores, a measure of recognition calculated by total “hits” minus false positives, following the day shift (5.9 ± 0.1) were also similar to those obtained following night float (5.8 ± 0.1) ($F[1,50] = 1.81$, $p = 0.18$) (see table 11). Similarly, % Retained scores on the RAVLT for day shift (90.3 ± 3.4) were not significantly different from those obtained following night float (89.1 ± 3.4) ($F[1,50] = 0.26$, $p = 0.61$) (see table 10). RAVLT Recognition Index scores following the day shift (13.2 ± 0.5) were similar to those obtained following night float work (13.1 ± 0.5) ($F[1,50] = 0.08$, $p = 0.77$) (see table 11).

Week-by-week comparisons of objectively measured learning were significant for both the BVMT-R ($F[3,48] = 2.94$, $p = 0.04$) and the RAVLT ($F[3,48] = 3.41$, $p = 0.02$) such that overall learning scores improved from week to week (see table 6).

Weekly comparisons of objectively measured memory were not found to be significantly different for any of the memory variables on the BVMT-R (Delayed Recall: ($F[3,48] = 0.58$, $p = 0.63$); % Retained: ($F[3,48] = 1.33$, $p = 0.28$); Recognition Index: ($F[3,48] = 2.10$, $p = 0.11$) or on the RAVLT (Delayed Recall: ($F[3,48] = 1.90$, $p = 0.14$; % Retained: ($F[3,48] = 1.97$, $p = 0.13$); Recognition Index: ($F[3,48] = 0.65$, $p = 0.59$). (See tables 7, 10, and 11, respectively).

CHAPTER NINE

STUDY 2 DISCUSSION

Medical residents in this study achieved equivalent total sleep time (hours slept/24 hours) while working day shift and night float (see table 4), as measured by actigraphy records, using a validated, automated, computer-algorithm to score sleep. However, this sleep equivalence was achieved in different ways, depending upon the shift worked. As illustrated in table 4, total sleep time (TST) on the day shift was obtained nearly entirely during off-shift hours at night, with little to no sleep on duty. In contrast, TST on the night float shift was obtained by combining a few sleep hours during the day off-shift hours with a few more hours obtained while on-duty. Specifically, residents slept nearly 7 hours during off-shift hours while working the day shift, compared to an average of a bit less than 4 hours during off-shift hours while working night float. On-duty sleep during the day shift averaged only 6 minutes, while on-duty sleep during night float was much longer, averaging 2.6 hours (see table 4 and figure 1).

This reduced daytime sleep obtained by the medical residents while working the night float is compatible with findings regarding sleep loss in other populations of shift workers working extended and/or night shifts (Akerstedt, 1998; Epstein et al., 2001). However, this study demonstrates that medical residents working the night float shift can obtain an equivalent to working the day shift amount of sleep over a 24 hour time period by combining their main sleep bout with supplemental naps taken while on duty on night float,. Since performance ultimately depends upon TST in a 24 hour period, it is no surprise that no differences in objectively measured performance were found between day shift or night float on either the PVT measures or the learning and memory measures (see tables 5, 6, & 7). This would be expected given the overall equivalence of TST between conditions and is consistent with the idea that

TST/24 hours is the primary determinant of performance, and not whether sleep is consolidated into a single sleep bout (Belenky et al., 2008; Mollicone, Van Dongen, & Dinges, 2007; Mollicone et al., 2008).

A recent focus of such research has been medical professionals, with an emphasis on obtaining an evidence-base to develop public policy with respect to medical resident work hours. As previously discussed in Chapter Two, the majority of research that has examined the effects of work hours on public safety have focused on the relationship between work hours and performance rather than the relationship between sleep and performance. As demonstrated here, it is necessary to investigate not only work hours, but also objectively measured total sleep obtained in 24 hours. While working the extended night float shift, the medical residents in our study were able to augment their restricted daytime sleep by napping during their night float shift. This resulted in objectively measured total sleep times equivalent to those obtained while working a normal day shift and thus preserved their subsequent objectively measured performance.

This study is unique in that it used objective measures of both sleep and performance in medical residents working normal day and extended night float shifts. As is the case with study 1, these results are important to the development of a fatigue-risk management system that will allow for optimal scheduling and rostering of medical professionals working such duty hours. These findings are also likely to be instrumental in the development of public policy that will protect not only the well-being and safety of medical residents, but their patients as well.

CHAPTER TEN

OVERALL DISCUSSION

There have been just two well-controlled laboratory studies investigating the effects of more than five consecutive days of sleep restriction on subsequent alertness and performance measures (Belenky et al., 2003; Van Dongen et al. 2003). As previously discussed, there are few published, naturalistic field studies that assess daily total sleep time in individuals as they meet occupational, societal, and domestic responsibilities over a week or more. Furthermore, there have been just two field studies in which the objective effects of variations of total sleep time on performance across a week or more have been studied (Landrigan et al., 2004; Lockley et al., 2004). The current studies sought to expand the available literature by investigating the effects of extended daytime and extended night float work hours on objectively measured sleep and performance as compared to normal daytime work hours over a period of time greater than one week.

In study 1, we found that extending work hours does, in fact, reduce overall objectively measured total sleep time. In this case, for each additional hour worked, a nearly equivalent amount of sleep was lost (see table 1). When work hours are extended, sleep appears to be the first activity to be truncated or dropped. This is consistent with findings from the American Time Use Survey (Basner et al., 2007) citing working hours as the most important factor in determining subsequent sleep time.

Contrary to expectations, objectively measured mean PVT RT performance was faster in the extended work hours condition compared to the normal work hours condition (see table 2). The potential reasons for this finding have been discussed in Chapter Five, with the most plausible being differences in circadian timing of test bouts.

In study 2, we found that medical residents obtained nearly equal amounts of objectively measured sleep while working both day and night float shifts (see table 3). However, depending upon the shift, medical residents obtained that sleep in very different ways. Napping on shift, while working the night float, allowed residents to augment their truncated daytime sleep, thus resulting in a total sleep time equivalent to that which they obtained while working day shift hours (see table 4 and figure 1).

In accordance with the equal total sleep time found between conditions, there were no objective performance differences detected, either using the PVT or the learning and memory measures (see tables 5, 6, & 7). This provides further evidence that performance depends upon total sleep time in a 24 hour time period and not upon whether sleep is consolidated into a single sleep bout (Belenky et al., 2008; Mollicone, Van Dongen, & Dinges, 2007; Mollicone et al., 2008). Indeed, napping may be the most effective way to counter fatigue, improving performance by increasing total sleep time (Akerstedt, 2003).

Limitations

There are limitations to these studies that should be taken into consideration when interpreting the results and planning future studies. A large number of these limitations are inherent to the nature of field studies. For example, lost or missing data due to research participant noncompliance or forgetfulness can be a problem. Equipment failure can also lead to missing data. Both subject noncompliance/forgetfulness and equipment failure occurred during the course of these studies to a minimal degree. Close contact was kept with all participants to prevent noncompliance.

As discussed in Chapter Two, alertness and cognitive performance (broadly defined as attention, vigilance, and learning/memory) can be measured in the field by added, simulator-derived, or embedded metrics. Added metrics include laboratory tests that have been ported to personal digital assistants (PDAs), such as the PVT used in these studies, and paper and pencil testing such as the BVMT-R and RAVLT that were used in study 2. Simulator-derived metrics include performance in simulated work environments (e.g. driving simulators or simulated work tasks). Embedded performance metrics are generally taken from the workplace (e.g. lane deviation sensors in commercial trucking, or performance evaluations within the workplace). One of the limitations of these studies is the use of only added metrics to measure performance. These types of metrics, while convenient, interrupt the normal flow of work and generally lack ecological validity. A much more robust measure of performance in a workplace environment would be an outcome relevant embedded metric. Embedded metrics (e.g., lane deviation in trucking) do not interrupt work flow and are ecologically valid.

Additional, unmeasured factors may have affected the results obtained in these studies. For example, caffeine has been shown to improve performance, even under conditions of fatigue (Wesensten, Belenky, Thorne, Kautz, & Balkin, 2004). Varying levels of caffeine consumption may have affected the outcomes in these studies. While laboratory studies typically control for dietary intake, we did not track dietary and substance intake in these field studies.

Increasing workload increases fatigue. Workload is hard to define and hence not easily measured in either laboratory or field studies. Typically, work load is operationally defined as task duration. It is conceivable that despite the decreased sleep obtained while working extended hours in study 1, that actual workload decreased, rather than increased, thus counteracting the effects of that sleep decrease on performance. Additionally, while study 2 found that medical residents were able to augment their off-shift main sleep bout with on-shift naps during their night float work hours, it may be that decreased workload during that time period also contributed to sustaining performance. The medical residents in study 2 may have had lighter workloads on night float as compared with day shift thus sparing performance.

Circadian rhythm, or time of day, is another factor affecting fatigue. In these studies, time of day for testing on the PVT may have been a factor. These are field studies and shift start and end times can vary naturally, so, testing bouts did not always occur at uniform times across conditions. Time of day for PVT may have affected the results in both studies. Test bouts for learning and memory testing were at the end of the night float (around 0700) and at the end of the day shift (1500-1700). This was the case for all of the medical residents and the order of the tests provided to them was counterbalanced. Thus, all testing was done at end of shift but for day shift this came in the late afternoon and for night float this came in the early morning. Again, this difference in timing of test bouts may have affected results.

A further limitation in these studies regards the learning and memory testing measures used. Measuring learning and memory requires other tests beyond the PVT, which was developed specifically to be free of learning effects and thus suitable to be used in a repeated measures paradigm. Practice, learning, and ceiling effects are all possibilities when they are used repeatedly as they were in study 2. While counterbalancing of the test order and using different forms of the tests were both done in study 2, it appears that a learning effect did occur week to week using these measures. Neuropsychological measures are typically not designed for use in non-clinical settings. It is conceivable that these tests were not well-suited to this group or that these measures tested aspects of learning and memory that were more resistant to sleep loss in this population.

Future Directions, Recommendations, and Conclusions

As discussed in Chapter Two, there has been much research in sleep and performance that has focused on the relationship between work hours and performance rather than the relationship between sleep and performance. Many studies have examined these factors in commercial trucking and railroad industries, the medical profession, and other shift workers. In contrast, few studies have focused on the ever-growing group of people who work extended work hours, either by extended hours in a single shift or by working multiple shifts in a 24-hour period (e.g. holding two jobs). In large measure, this research has also neglected the fact that total sleep time (i.e. main sleep period plus naps) in 24 hours is the primary determinant of sustained performance. The potential exists for increasing total sleep time by optimizing scheduling and providing adequate main sleep and nap opportunities, thus sustaining subsequent alertness and performance and productivity, safety, health, and well-being.

These present studies demonstrate two clear and important findings. One, extending work hours results in reduced overall objectively measured total sleep time. And two, when extended work hours or timing of work hours restrict the duration of the main sleep bout, adequate total sleep time in 24 hours may be achieved by supplementing the main sleep bout with naps with some naps taken on shift. The obvious recommendation based upon these findings is to increase total sleep time by optimizing scheduling. For example, scheduling night float as an extended work time period, with opportunities for strategically placed sleep built into the schedule. Through doing this, employees would be able to work the necessary shift and augment their restricted daytime sleep with naps during the night, subsequently leading to better maintained alertness and performance and hence increased productivity, safety, and worker well-being.

These studies have further application to the broader issues of sleep and performance including public policy making, fitness for duty standards development, schedule optimization, and education for shift workers, and are essential to the emerging art and science of fatigue risk management. A notable success in the translation of research into recommendations for practice is the effect of field studies of sleep and performance in medical residents on the recent Institute of Medicine report (2008) on resident duty hours.

Field studies using objective measures of sleep and performance, such as the ones presented here, will be instrumental to forming the evidence-base of a fatigue risk management system. Such a system would allow for the management of sleep and duty times to sustain optimal performance in the workplace. Objectively measured sleep/wake histories recorded in field studies can be used to predict performance, albeit retrospectively, on a minute to minute basis through the use of biomathematical sleep/performance prediction models (Hursh et al., 2006; Mallis et al., 2004). Further validation and development of these models through objective evidence gathered in field studies of sleep and performance will enable fatigue risk management.

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APPENDIX

Table 1. Summary of shift duration and of objective sleep per 24 hours (as measured by actigraphy using a sleep scoring algorithm) by condition for Study 1. Employees lost approximately an hour of sleep for each additional hour worked.

Condition	Shift Duration (hrs)	S.E.	Objectively Measured Sleep/24hrs (hrs)	S.E.
Normal Working Hours	9.1*	0.2	6.9*	0.2
Extended Working Hours	10.3*	0.3	6.0*	0.2

*$p < 0.01$

Table 2. Summary of mean PVT RT performance and PVT lapses by condition in Study 1. Despite extended work hours, mean RT improved and lapses decreased.

Condition	Mean PVT RT(ms)	S.E.	Lapses	S.E.
Normal Working Hours	326*	13	4.9*	0.9
Extended Working Hours	303*	13	2.2*	0.9

*$p < 0.01$

Table 3. Summary of shift duration in Study 2. Medical residents worked significantly longer hours during night float than they did during day shift work.

Condition	**Shift Duration (hrs)**	**S.E.**
Day Shift	9.0*	0.2
Night Float	13.4*	0.2

*$p < 0.01$

Table 4. Summary of objectively measured sleep duration on and off shift and total sleep time in 24 hours (as measured by actigraphy scored for sleep/wake by a computerized, validated sleep scoring algorithm) for day shift and night float for Study 2. Medical residents slept significantly less off shift while working night float than they did while working days. This restricted off shift sleep while working night float was supplemented by sleeping on shift. As a result of this supplemental sleep obtained on shift during night float, the amount of sleep obtained/24 hours while working night float was not significantly different from the amount of sleep obtained/24 hours while working day shift.

Condition	**Objectively Measured Sleep Off Shift (hrs)**	**S.E.**	**Objectively Measured Sleep On Shift (hrs)**	**S.E.**	**Objectively Measured Sleep/24 hrs (hrs)**	**S.E.**
Day Shift	6.8*	0.2	0.1*	0.2	7.0	0.3
Night Float	3.8*	0.2	2.6*	0.2	6.8	0.2

*$p < 0.01$

Table 5. Summary of mean PVT RT performance and PVT lapses between conditions for Study 2. Consistent with equal objectively measured total sleep time between conditions, no differences in mean RT or lapses were found between conditions.

Condition	Mean PVT RT (ms)	S.E.	Lapses	S.E.
Day Shift	382	28	10.1	2.7
Night Float	393	28	11.1	2.7

Table 6. Summary of BVMT-R and RAVLT Total Recall scores by week in Study 2. Scores on both measures improved on a week to week basis.

Week	Condition	BVMT-R Total Recall Score	S.E.	RAVLT Total Recall Score	S.E.
1	Day	23.5*	1.3	56.8*	1.8
2	Night	26.3*	1.3	58.1*	1.8
3	Night	26.9*	1.3	57.4*	1.8
4	Day	27.5*	1.3	61.6*	1.8

* $p < .05$

Table 7. Summary of BVMT-R and RAVLT Delayed Recall scores by week in Study 2. No changes were evident from week to week on either measure.

Week	Condition	BVMT-R Delayed Recall Score	S.E.	RAVLT Delayed Recall Score	S.E.
1	Day	9.9	0.5	11.8	0.7
2	Night	9.8	0.5	11.9	0.7
3	Night	9.3	0.5	12.5	0.7
4	Day	10.1	0.5	12.8	0.7

Table 8. Summary of sleep by week (as measured by actigraphy using a sleep scoring algorithm) for Study 2. No differences were found in estimated total sleep times from week to week.

Week	**Condition**	**Objectively Measured Sleep/24 hours (hrs)**	**S.E.**
1	Day	6.9	0.3
2	Night	6.6	0.3
3	Night	7.0	0.3
4	Day	7.1	0.3

Table 9. Summary of mean PVT RT performance and PVT lapses by week in Study 2. Mean RT was found to be slower on a week to week bases, while lapses likewise increased from week to week.

Week	Condition	Mean RT(ms)	S.E.	Lapses	S.E.
1	Day	353*	29	7.5*	2.7
2	Night	384*	29	10.3*	2.7
3	Night	401*	29	11.8*	2.7
4	Day	412*	29	12.9*	2.7

* $p < 0.01$

Table 10. Summary of BVMT-R and RAVLT % Retained scores by week in Study 2. No differences were found in either measure on a week to week basis.

Week	Condition	BVMT-R % Retained Score	S.D.	RAVLT % Retained Score	S.D.
1	Day	99.8	3.1	90.5	3.8
2	Night	92.6	3.1	85.1	3.8
3	Night	92.5	3.1	93.1	3.8
4	Day	93.2	3.1	90.2	3.8

Table 11. Summary of BVMT-R and RAVLT Recognition Index scores by week for Study 2. No differences were found in either measure on a week to week basis.

Week	Condition	BVMT-R Recognition Index Score	S.D.	RAVLT Recognition Index Score	S.D.
1	Day	5.8	0.1	13.5	0.5
2	Night	5.7	0.1	13.1	0.5
3	Night	5.9	0.1	13.1	0.5
4	Day	6.0	0.1	12.9	0.5

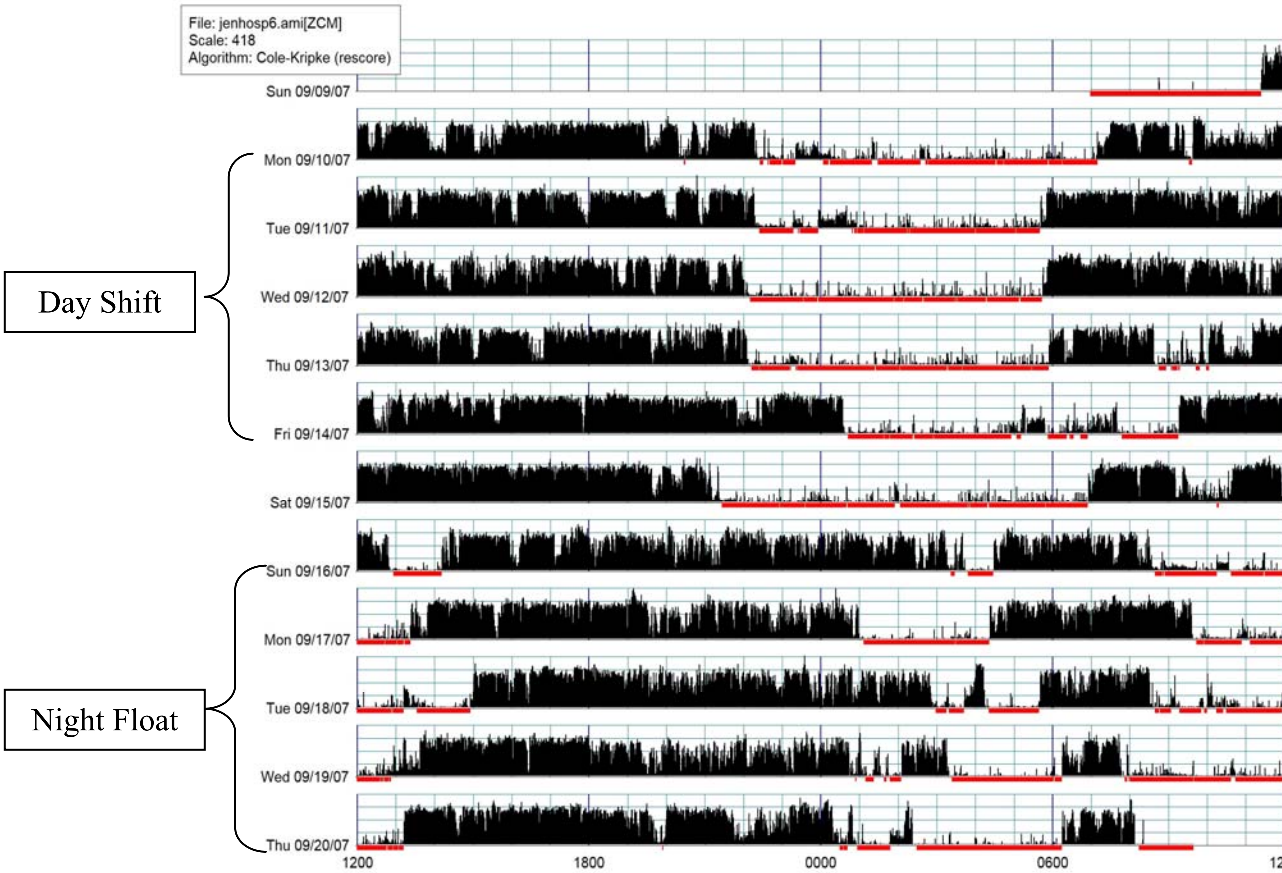

Figure 1: Example actigraphy record from medical resident in Study 2. Time of day is referenced at bottom of figure, from noon to noon in a 24 hour period. Successive days are referenced on the left of the figure from top to bottom. Condition is noted at left. Periods of objective sleep as scored from the actigraph record using a validated, sleep-scoring algorithm are underlined in red. Day shift sleep/24 hours is obtained primarily during a single bout at night while off shift. Night float sleep/24 hours is obtained in several bouts, with a main bout during the day while off shift