COGNITIVE CONSEQUENCES OF SLEEP DEPRIVATION, SHIFT WORK, AND HEAT EXPOSURE FOR UNDERGROUND MINERS

by
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Abstract

The extent to which an underground miner's alertness is influenced by sleep deprivation, shift work, and working in elevated temperatures is currently unknown. Actigraphy and psychomotor vigilance data were collected from nineteen underground miners over 28 consecutive days. Core body temperature data was also gathered during four scheduled work shifts. Participants experienced shortened sleep durations and poor sleep efficiency throughout the study. Significant increases in reaction time occurred over the course of night shifts, a decline that was not observed during day shifts. A strong, negative correlation between core body temperature and reaction time was present throughout day shifts but did not appear during night shifts. Poor sleep and altered circadian rhythms appear to negatively affect the alertness of participants during work times. An inadequate adaptation to night work schedules may be indicated by the poor alertness and absent relationship between core body temperature and performance observed during night shifts.

Keywords

Sleep deprivation, shift work, heat stress, circadian rhythms, underground mining, occupational health and safety

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Chapter 1

1 Introduction

To alleviate the risk of occupational injury and disease, modern workplaces are increasingly promoting and maintaining occupational health and safety. Yet despite these efforts tragedy still strikes in the form of occupation-related accidents. Historical workplace tragedies such as the near nuclear meltdown in Chernobyl, the Union Carbide gas leak in Bhopal, and the Exxon Valdez oil resulted in vast numbers of injuries and fatalities (Dinges, 1995; Folkard & Lombardi, 2006). More recently, occupation-related disasters such as the 2013 West Fertilizer Company Explosion in Texas (Santos & Krauss, 2013), the 2013 Yarnell Hill Fire (a wildfire responsible for the deaths of 19 firefighters) (Coe, Merrill, & Lee, 2013), and the 2010 Chilean Mining Accident (Siddique, 2010) have garnered media attention. Although impossible to determine what proportion of workplace accidents have resulted from human error, it is likely that some of these incidents were preventable.

Workplace injuries and illnesses are associated with substantial human and financial costs. In 2012 the Association of Worker's Compensation Boards of Canada (AWCBC) reported 977 workplace fatalities, or nearly 3 on-the-job fatalities each day of the year. Ontario reported the greatest number of occupation-related deaths in 2012: 306, accounting for nearly one-third of Canadian occupational mortalities that year. Employment sectors disclosing the greatest proportion of fatalities included construction (21.6%), manufacturing (18.7%), government services (11.1%), and mining (7.1%) (AWCBC, n.d.).

In addition, AWCBC statistics show that nearly a quarter of a million (245,365) workplace injuries or illnesses resulting in a worker receiving compensation for lost wages (accepted lost-time injuries) occurred in 2012 (AWCBC, n.d.); however, this number does not represent injuries in which workers were not compensated for lost wages or injuries to workers who do not fall under the regulated Workers Compensation system (e.g. self-employed individuals). Furthermore, Shannon and Lowe (2002) have suggested that occupational injuries are often under-reported. An estimated 40% of individuals who suffer an occupational injury and are eligible for Workers' Compensation do not submit a claim. When considering both direct and indirect costs, the estimated economic burden of workplace injuries and illnesses in Canada is more than $19 billion annually (Gilks & Logan, 2010). These enormous costs suggest the importance of determining how and why these injuries are occurring, essential information for developing best practices and policies that may mitigate employee illness and death.

1.1 Health and Safety Hazards for Underground Miners

Work in the mining sector is arduous and often dangerous. Despite employing only 1% of the global workforce, the mining industry is responsible for approximately 8% of work-related fatalities worldwide (8.2% in Canada) (AWCBC, n.d.; Jennings, 2011). This large proportion of fatal accidents is due in part to the numerous workplace hazards that exist for the nearly 30 million employees working in mines (Donoghue, 2004). Accordingly, recognizing and alleviating occupational hazards in the mining industry is essential for the prevention of future workplace disasters and fatalities (McPhee, 2004).

Due to the diverse nature of the mining sector, many workplace hazards exist for mine workers (Donoghue, 2004; Jennings, 2011; Joyce, 1998; McPhee, 2004). Factors such as the location of the mine (industrialized country or non-developed country), where mining operations take place (surface or underground), or even the commodity being harvested (coal or mineral) influence the type of occupational dangers workers may encounter (Amponsah-Tawiah et al., 2013; Cho & Lee, 1978; Kunar, Bhattacherjee, & Chau, 2008; McPhee, 2004). In addition, occupational hazards for employees may vary from task to task or even shift to shift as conditions such as weather, mine geography, and the condition of mining equipment fluctuate (Joyce, 1998). Mining occupational hazards have previously been described as encompassing five categories: biological, chemical, physical, ergonomic, and psychosocial (Donoghue, 2004).

1.1.1 Biological Hazards

Biological hazards in mines are becoming less of a concern as sanitation in mines improves, however some hazards still remain (Donoghue, 2004). Contact with bacteria-contaminated water or soil, primarily in developing countries, may result in infections such as leptospirosis (Weil's disease, a bacterial infection) or ankylostomiasis (a hookworm infection) (Cho & Lee, 1978; Donoghue, 2004; Dutkiewicz, Jabloński, & Olenchock, 1988).The hot, humid environments found in underground mines also make it possible for bacteria such as *Legionella*, the bacteria responsible for Legionnaires' Disease, and the fungus responsible for dermatophytosis (ringworm) to thrive (Australian Standard, 2003; Cho & Lee, 1978). Working in remote, tropical mining locations also presents a risk of developing diseases such as malaria and dengue fever (Donoghue, 2004).

1.1.2 Chemical Hazards

The airborne chemicals present in mining environments are major occupational hazards (Cho & Lee, 1978; Joyce, 1998; Ross & Murray, 2004). Dust exposure may seem benign but once inhaled dust can settle in the lungs triggering inflammation of the tissue and fibrous scarring of the alveoli (Joyce, 1998; Ross & Murray, 2004). After several years of dust exposure the progressive fibrosis occurring in the lungs makes the remaining tissue stiff resulting in an irreversible decline in respiratory function (Joyce, 1998; Ross & Murray, 2004). This progressive respiratory disease is referred to as pneumoconiosis. Coal worker's pneumoconiosis (caused by coal dust) and silicosis (a result of silica dust) are both frequently found in underground miners; however, chronic inhalation of any mineral dust may have a similar outcome (Joyce, 1998; Ross & Murray. 2004).

Despite the drastic reduction of asbestos use in mines, asbestos remains a hazard to miners (Donoghue, 2004; Ross & Murray, 2004). Inhalation of asbestos results in pleural plaque formation (scarring of the lung lining); these plaques are considered the hallmark of asbestos exposure. Respiratory dysfunction and an increased risk of mesothelioma and lung cancer have been associated with the development of pleural plaques (Bourbeau et al., 1990; Ross & Murray, 2004). In addition, inhalation of asbestos may result in pulmonary fibrosis and pneumoconiosis similar to that observed in those exposed to coal and mineral dust. This variety of pneumoconiosis is referred to as asbestosis, and often results in restricted lung function (Cho & Lee, 1978; Ross & Murray, 2004).

Many other chemical inhalation hazards exist in mines. Diesel emissions are especially prevalent in underground mines where miners and machinery work in enclosed spaces with limited ventilation (Donoghue, 2004). Temporary exposure to diesel exhaust may result in coughs, headaches, and reversible declines in lung function (Joyce, 1998); however, chronic inhalation of diesel exhaust, a known carcinogen, increases the risk of developing lung cancer. Exposure to other carcinogens such as nickel compounds, arsenic, and coal tar pitch can also increase the risk of developing lung cancer (Donoghue, 2004; Joyce, 1998). In addition, gases, both toxic and non-toxic are present in mines. Inhalation of toxic gases such as carbon dioxide, carbon monoxide, and hydrogen sulfide can be fatal (Cho & Lee, 1978). Non-toxic gases such as methane are highly combustion and may be deadly if ignited (Cho & Lee, 1978).

1.1.3 Physical Hazards

The physical environment and ambient conditions present in a mine setting may create potential dangers for mine workers. Physical hazards such as rock falls, fires, cave-ins, explosions, mobile equipment accidents, electrocution, and even flooding are largely unpredictable and may lead to near-misses or traumatic accidents (Donogue, 2004; Joyce, 1998). In addition, elevated air temperatures and humidity in underground mines increases the risk of dehydration and/or heat stress in workers (Cho & Lee, 1978; Donoghue, 2004; Joyce, 1998; Donoghue, Sinclair, & Bates, 2000).

Various physical mining hazards can also lead to permanent disability or injury after chronic exposure. Prolonged and repeated exposure to excessive noise from heavy machinery, blasting, and ancillary equipment (for example, fans and blowers used for ventilation) can lead to permanent hearing loss (Joyce, 1998; McBride, 2004). As a result noise-induced hearing loss (NIHL) is prevalent in mine workers. As many as 90% of coal miners and 49% of metal miners experience NIHL compared to 10% of individuals in an age-matched sample (Franks, 1996). In addition, operating poorly maintained equipment (e.g. mobile vehicles and vibrating tools) may create ergonomic issues resulting in musculoskeletal and/or circulatory disorders (Donoghue, 2004; McPhee, 2004).

1.1.4 Ergonomic Hazards

Ergonomic hazards develop when a “mismatch” exists between the worker and their environment in turn leading to declines in worker safety and productivity (Stubbs, 2000). These hazards can be considered physical or psychosocial in nature (Donoghue, 2004; McPhee, 2004). Physical ergonomic hazards often contribute to cumulative trauma disorders (CTDs), also referred to as musculoskeletal disorders (MSDs) or repetitive strain injuries (RSIs), the most common occupational diseases in mining (NIOSH, 2000). Developing a CTD may result in prolonged disability, a concern that is especially relevant for the aging, mining workforce whose risk of injury is already elevated (Joyce, 1998; McPhee, 2004).

Whether completing manual or mechanized tasks, mine workers are constantly exposed to hazards that may precipitate traumatic injuries. For example, uneven floors, slippery surfaces, poor lighting, and heavy objects are hazards that may cause a slip, trip, or fall during the manual handling of loads (Cho & Lee, 1978; McPhee, 2004). Repetitive lifting of loads or using improper/awkward lifting postures during manual handling can also result in muscle strain or further injury (McPhee, 2004; NIOSH, 1997). Furthermore, poorly designed personal protective equipment (PPE), such as hard hats, can also create issues with visibility or neck discomfort for miners (Godwin, 2013).

Ergonomic hazards associated with operating heavy machinery or driving vehicles include maintaining awkward postures (sitting or standing) for prolonged periods of time, poor line of sight, whole-body vibration (WBV), and also hand- and foot-transmitted vibration (Eger et al., 2010; Godwin et al., 2007; Leduc et al., 2011). These hazards contribute to the development of MSDs (particularly lower back) and blood circulatory disorders (e.g. hand-arm vibration syndrome and vibration-induced white foot) (Leduc et al., 2011; McPhee, Foster, & Long, 2009; NIOSH, 1997). Poorly designed or inadequately maintained equipment and "rough rides" (jarring rides over uneven roads) are major contributors to WBV (Eger, Contratto, & Dickey, 2011; McPhee, 2004; McPhee et al., 2009). Both the sudden jolts and steady state vibration that occur during rough rides may exacerbate preexisting lower back and neck injuries (McPhee, 2004).

Psychosocial ergonomic hazards contribute to worker fatigue, stress, decreased safety experience (near misses, incident of accident with no injury, etc.), and overall poor health in miners (Amponsah-Tawiah et al., 2013; Donoghue, 2004; Driscoll, 2007). Some of these hazards include shiftwork and extended shifts resulting in sleep deficits; higher workloads; inadequate break time; monotonous tasks with little variation between tasks; and limited job control (Amponsah-Tawiah et al., 2013; Donoghue, 2004; McPhee, 2004; Joyce, 1998). The stress created by these psychosocial factors can lead to disturbed sleep and family problems creating further stress as well as exacerbating physical illnesses (Joyce, 1998; Theorell, 2000).

1.1.5 Psychosocial Hazards

Although often overlooked, the presence of psychosocial hazards in mining environments can be detrimental for workers (Driscoll, 2007; Kunar, Bhattacherjee, & Chau, 2008). Psychosocial hazards such as harassment and bullying; work pressure and low job control; lengthy work hours and shift work; as well as working away from home, all present a risk for mental stress and illness (Driscoll, 2007). Profoundly influential events, like being involved in or witnessing a traumatic injury or fatality, are also major contributors to mental stress and illness (e.g. post-traumatic stress disorders) in workers (Donoghue, 2004; Kowalski-Trakofler & Vaught, 2012). Increased mental stress and illness may contribute to decreased productivity, increased absenteeism, and declines in overall physical health (Driscoll, 2007). Drug and alcohol abuse in workers may be the result of, or possibly the precursor to, experiencing psychosocial hazards (Driscoll, 2007; Kunar, Bhattacherjee, & Chau, 2008).

The experience of psychosocial hazards may leave workers prone to occupation-related accidents and injuries (Kunar, Bhattacherjee, & Chau, 2008; Paul & Maiti, 2007 & 2008). Hazards such as poor health status, increased job stress, job dissatisfaction, and risk taking behaviour (e.g., unsafe work practices) increase the likelihood of underground miners experiencing a workplace accident (Kunar, Bhattacherjee, & Chau, 2008; Paul & Maiti, 2007 & 2008). In addition, job stress, irregular work schedules, and long work hours create a hazard by decreasing the amount of sleep mine workers are able to attain. Chronic sleep reduction may leave workers prone to elevated levels of sleepiness and fatigue, as well as diminished cognitive function, increasing the likelihood of human-error related accidents in the workplace (Åkerstedt et al., 2002a; Costa, 2003; Salminen et al., 2010).

1.2 Sleepiness and Fatigue

While on the job, both fatigue and sleepiness are potentially hazardous altered states for workers. Although often considered synonymous by medical professionals and the general population, fatigue and sleepiness are two distinct phenomena (Hossain et al., 2005; Neu et al., 2011; Pigeon, Sateia, & Ferguson, 2003; Shahid, Shen, & Shapiro, 2010). While they are frequently occurring simultaneously, fatigue and sleepiness are discernible by their unique manifestations and aetiologies (Shen, Barbera, & Shapiro, 2006). Differentiating between sleepiness and fatigue is crucial for the accurate assessment and treatment of the symptoms associated with these conditions.

1.2.1 Defining Sleepiness

Previously, sleepiness has been described in terms of “subjective sleepiness” and “objective sleepiness” (Shen, Barbera, & Shapiro, 2006). Subjective sleepiness is denoted as a feeling of drowsiness; whereas objective sleepiness refers to sleep propensity, the drive or tendency to fall asleep (Dement, 1993; Neu et al., 2011; Pigeon et al., 2003; Rogers, 2008; Shen, Barbera, & Shapiro, 2006). Sleepiness may be a consequence of sleep loss, prolonged periods of wakefulness, circadian disruption, medication, and/or sleep pathology (Åkerstedt et al., 2002b; Guilleminault & Brooks, 2001; Mathis, Seeger, & Ewert, 2003; Ruggles & Hausman, 2003).

Excessive sleepiness increases an individual's likelihood of falling asleep at inappropriate times (e.g. while driving or performing work-related duties) and is considered pathological (Åkerstedt et al., 2002b; Shahid et al., 2010). Even brief intrusions of sleep (15-30 seconds), known as microsleeps, during daytime activities may potentially result in unsafe lapses of attention (Banks & Dinges, 2007; Durmer & Dinges, 2005). Accordingly, excessive sleepiness is associated with increased occupational injuries in non-shift day workers (Melamed & Oksenberg, 2002) and shift workers (Lindberg et al., 2001; Suzuki et al., 2005), as well as a greater risk for motor vehicle accidents (Masa, Rubio, & Findley, 2000; Mathis, Seeger, & Ewert, 2003; Pizza et al., 2010). It is estimated that excessive daytime sleepiness affects 3-22% individuals in the general population (Hara, Lopes Rocha, & Lima-Costa, 2004; Hossain et al., 2003; Masa, Rubio, & Findley, 2000; Melamed & Oksenberg, 2002; Young, 2004) and 5-15% of first-contact (i.e. primary care) patients (Hossain et al., 2003; Shapiro, 1998; Shen, Barbera, & Shapiro, 2006).

1.2.2 Measuring Sleepiness

Sleepiness has been evaluated by medical professionals and researchers using both subjective and objective measures. Methods of measuring the subjective perception of sleepiness include the Standford Sleepiness Scale (SSS) (Hoddes, Dement, & Zarcone, 1972), the Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg, 1990), the Epworth Sleepiness Scale (ESS) (Johns, 1991), and many others (Shahid et al., 2010). The SSS and KSS employ likert-rating scales to allow the test-taker to select the number which corresponds to the severity of sleepiness they are currently experiencing (Åkerstedt & Gillberg, 1990; Hoddes, Dement, &

Zarcone, 1972). This method allows for the depiction of any dynamic changes in sleepiness over a short time (Shahid et al., 2010). In contrast, the ESS has the test-taker predict the degree of sleepiness they are likely to experience in a set of given situations (rated on a likert scale) (Johns, 1991). This technique provides a representation of the participant's static, or global, level of sleepiness (Shahid et al., 2010). Previous studies have shown that the KSS and other subjective ratings of sleepiness are positively correlated with increases in reaction time and attentional lapses (Horne & Burley, 2010; Kaida et al., 2006). A negative correlation between subjective sleepiness and the number of hours slept prior to evaluation has also been established (Breslau et al., 1997). In addition, Johns (2000) proposed that a subjective report, specifically the ESS, was a more accurate predictor of sleepiness than objective measures in both healthy individuals and narcoleptics.

Conversely, many laboratory studies have revealed that ratings of subjective sleepiness increased after initial sleep loss but plateaued after prolonged sleep deprivation (Belenky et al., 2003; Carskadon & Dement, 1981; Philip et al., 2012; Van Dongen et al., 2003). Furthermore, these studies indicated that while subjective sleepiness stabilized, cognitive performance continually declined as sleep loss persisted. These findings suggest that sleep loss may attenuate the subjective perception of sleepiness, leaving individuals unable to determine their true level of impairment (Belenky et al., 2003; Van Dongen et al., 2003).

Due to the disparity in perceived sleepiness created by sleep loss, objective measures of daytime sleepiness continued to be regarded as the "gold standard" of measurement (Balkin et al., 2004; Pigeon et al., 2003; Shahid et al., 2010). Objective tests used to evaluate sleep latency include the Multiple Sleep Latency Test (MSLT) (Carskadon & Dement, 1977; Richardson et al., 1978) and the Maintenance of Wakefulness Test (MWT; Milter, Gujavarty, & Browman, 1982).

These instruments are utilized to quantify two factors which influence sleep propensity: sleep tendency and ability to stay awake, or “wakefulness”, respectively (Pigeon et al., 2003; Shahid et al., 2010; Shen, Barbera, & Shapiro, 2006). The MSLT and MWT (a variant of the MSLT) use standard electrophysiological measures [electroencephalography (EEG) and electrooculography (EOG)] to determine an individual’s sleep latency throughout four to five daytime nap opportunities (Carskadon & Dement, 1982). Sleep latency is operationalized as the time between test initiation and sleep onset, determined using EEG variables.

A decrease in sleep latency during the MSLT indicates a greater degree of sleepiness (Durmer & Dinges, 2005; Kluge et al., 2012) whereas shortened sleep latencies during the MWT suggest a decrease in an individual’s ability to resist sleep (Shen, Barbera, & Shapiro, 2006). When evaluated with both the MSLT and MWT, incongruent sleep latencies often occur and are reflective of the separate “drives” that the tools measure (Sangal, Thomas, & Mitler, 1992). However, sleep latencies of the MSLT and the MWT have shown small but significant correlations when measured in the same sample of participants (Sangal et al., 1997; Sangal et al., 1992). One limitation of the MSLT and MWT is the lack of generalizability of the laboratory results obtained, suggesting that these measures are poor predictors of sleep propensity in real-world scenarios (e.g. while at work or while driving a vehicle) (Johns, 2000).

1.2.3 Defining Fatigue

Previous literature has demonstrated that the experience of fatigue, although universal, is poorly understood (Chalder et al., 1993). The lack of operationalization surrounding fatigue is likely a consequence of the non-specific, multifaceted, and primarily subjective nature of the phenomenon (Hossain et al., 2003, 2005; Ream & Richardson, 1996; Shahid et al., 2010; Shen, Barbera, & Shapiro, 2006). Consequently, a working definition for fatigue remains elusive, leaving the term ill-defined and under-emphasized in the literature (Åkerstedt et al., 2004; Hossain et al., 2003; Ream & Richardson, 1996). Due to the poorly define construct of fatigue, estimated prevalence ranges widely from 20-25% in the general population (Pigeon et al., 2003; Shen, Barbera, & Shapiro, 2006) and 6-45% in primary care patients (Hossain et al., 2005; Lewis & Wessely, 1992; Shahid et al., 2010). In order to better operationalize the multiple facets of fatigue, many healthcare professionals and researchers have utilized a dualistic approach (Aaronson et al., 1999; Shen, Barbera, & Shapiro, 2006). For example, fatigue has been dichotomized by duration of symptoms, whether acute or chronic, or in regard to the source and/or characteristics of the symptoms, such as mental vs. physical or physiological vs. psychological.

While acute fatigue is considered a consequence of the strains associated with everyday life, persistent and frequent fatigue may be a sign of illness (Hossain et al., 2005; Ream & Richardson, 1996). Aaronson and colleagues (1999) stated that acute or “normal” fatigue occurs due to exertion, like that experienced after exercising or concentrating, and is alleviated with rest rather than sleep. Acute fatigue is also considered to be a protective function of the body (Piper, 1989; Shen, Barbera, & Shapiro, 2006). In contrast, chronic or “pathological” fatigue is described as unusual or excessive in nature and is not relieved by rest (Aaronson et al., 1999; Ream & Richardson, 1996). Changes in health status (i.e. disease or pregnancy) typically result in chronic fatigue (Aaronson et al., 1999; Piper, 1989; Ream & Richardson, 1996; Shen, Barbera, & Shapiro, 2006). Both “mental” and “physical” classifications have been used to designate sources of acute fatigue (Berryman, Lukes, & Keller, 2009; Brake & Bates, 2001; Milligan, Lenz, Parks, Pugh, & Kirtzman, 1996).

Mental, or psychological, fatigue is characterized by temporary cognitive impairments, reduced motivation, and increased weariness (Aaronson et al., 1999; Åkerstedt et al., 2004; Shen, Barbera, & Shapiro, 2006). Declines in physical performance have also been associated with mental fatigue (Marcora, Staiano, & Manning, 2009). Often associated with stress, mental fatigue occurs when demands (both internal and external) exceed available resources (Aaronson et al., 1999). Additionally, mental overload (prolonged cognitive exertion) and underload (boredom or monotony) may also lead to the experience of mental fatigue (Brake & Bates, 2001; Marcora et al., 2009). Mood disorders such as depression and anxiety are commonly accompanied by mental fatigue (Aaronson et al., 1999; Lee, Hicks, & Nino-Murcia, 1991; Shen, Barbera, & Shapiro 2006).

On the other hand, physical fatigue is a reversible decrease in the ability to exert force subsequent to muscle weakening (Bigland-Ritchie et al., 1995; Lorist et al., 2002). Physical fatigue may develop due to physiological disturbances such as hyperthermia, depleted glycogen stores in muscles, and muscle soreness after overuse (Brake & Bates, 2001). The terms motor fatigue (Lorist et al., 2002), muscle fatigue (Enoka & Duchateau, 2008), and physiological fatigue have all been used to describe physical fatigue.

Disparity in the literature has led to confusion surrounding the definition of physiological fatigue. Many authors have defined physiological fatigue as acute fatigue, a loss in voluntary force-generating capacity in the muscles (Lewis & Haller, 1991; Kent-Braun, 1999; Piper, 1989; Shahid et al., 2010; Shen, Barbera, & Shapiro, 2006; Zwarts, Bleijenberg, & van Engelen, 2008). Alternatively, physiological fatigue has been described as functional organ failure resulting from excessive energy consumption (Aaronson et al., 1999; Berger et al., 1991). Acute physiological fatigue is commonly linked to sleep disturbances, infection, and anemia (Aaronson et al., 1999; Zwarts et al., 2008).

Some authors have further categorized acute physiological fatigue as originating from either central nervous system (CNS) or peripheral nervous system (PNS) sources (Aaronson et al., 1999; Kent-Braum, 1999; Shen, Barbera, & Shapiro, 2006). For example, fatigue from a central origin could arise from dysfunction in a specific area of the CNS, such as the motor cortex, whereas fatigue from a peripheral source could include impaired transmission between nerves and muscles (Zwarts et al., 2008). Alternatively, researchers have also suggested that peripheral and central fatigue refers to fatigue of physical or psychological (see above) origin respectively (O'Dell, Meighen, & Riggs, 1996).

Using a dualistic approach to conceptualize fatigue alleviates some ambiguity created by its' inadequate definition but understates the complexity and multidimensional nature of the phenomenon (Shen, Barbera, & Shapiro, 2006). In addition, overlap in nomenclature still occurs due to the use of broad categorizations when delineating the features of fatigue. In this regard, the subclasses of fatigue will not be differentially considered for the purposes of this thesis. Furthermore, fatigue will be operationalized in terms of the following definition, "an overwhelming sense of tiredness, lack of energy and a feeling of exhaustion, associated with impaired physical and/or cognitive functioning" (Shen, Barbera, & Shapiro, 2006, p. 70).

Sleepiness and fatigue often develop concurrently following sleep restriction and sleep disruption (Shen, Barbera, & Shapiro, 2006). This comorbid expression of fatigue and sleepiness is commonly found in sleep pathologies such as obstructive sleep apnea and periodic limb movement disorder (Aldrich, 2000; Hossain et al., 2005); however, previous studies have revealed that despite their co-expression, ratings of subjective fatigue and subjective sleepiness are poorly correlated in clinical populations (Hossain et al., 2005; Johns, 1991). Primary insomnia and narcolepsy are prime examples of sleep disorders in which the experience of fatigue and sleepiness are dissociated (Hossain et al., 2005). Individuals suffering from primary insomnia usually describe elevated levels of fatigue without a subsequent increase in sleepiness (Aldrich, 2000; Hossain et al., 2005; Johns, 1991). Conversely narcoleptics experience pathological sleepiness but little to no change in fatigue levels (Abbey & Shapiro, 1995).

1.2.4 Measuring Fatigue

Fatigue is a difficult phenomenon to quantify due to its overtly subjective nature. The paucity of objective assessment tools that exist for the objective measurement of fatigue is likely a contributing factor to the poor understanding and operationalization of fatigue; however, the perception of fatigue can be evaluated using a variety of subjective rating scales. Measures such as the Fatigue Symptom Inventory (FSI; Hann, Denniston, & Baker, 2000), the Fatigue Severity Scale (FSS; Krupp et al., 1989), and the Fatigue Impact Scale (FIS; Fisk et al., 1994) are just a few of the scales that have been utilized to assess fatigue severity, duration of fatigue, as well as the impact fatigue has on daily functioning and/or quality of life (Pigeon et al., 2003; Shahid et al., 2010; Shen, Barbera, Shapiro, 2006). Although no "gold standard" assessment exists for the direct quantification of fatigue, the influence of fatigue on cognitive and motor performance can be evaluated and utilized as an indirect measure of fatigue (Lee et al., 2010).

1.2.5 Quantifying the Cognitive Consequences of Fatigue and Sleepiness

Impairment in cognitive function is the most rapidly occurring, unavoidable effect of sleep loss (Cirelli & Tononi, 2008). Studies show that even minimal amounts of sleep deprivation result in fatigue, sleepiness, and cognitive dysfunction (Belenky et al., 2003; Killgore et al., 2009; Nilsson et al., 2005; Van Dongen et al., 2003). Cognitive deficits that arise subsequent to an inadequate amount of sleep or quality of sleep include decreases in alertness, vigilance, working memory, concentration, and problem-solving ability (Belenky et al., 2003; Van Dongen et al., 2003). These mental processes, referred to as executive functions, are especially prone to impairment after sleep loss. This dysfunction is due to the execution of these processes in the prefrontal lobe, a structure that is particularly sensitive to sleep loss (Harrison et al., 2000; Nilsson et al., 2005). By measuring the degraded function of cognitive processes researchers can better determine the extent of the deficits arising from sleep loss and fatigue.

The Behavior Rating Inventory of Executive Function-Adult version (BRIEF-A; Beebe et al., 2002; Roth, Isquith & Gioia, 2005) is an example of a subjective measure which may aid in determining the relationships between sleep disruption and cognitive dysfunction. The BRIEF-A is a standardized questionnaire used to assess impairment of executive functioning in individuals 18 and older (Roth, Isquith & Gioia, 2005). Individuals who obtain a T-score ($M = 50$, $SD = 10$) within the clinical range (65 and greater) on any of the BRIEF-A scales may be experiencing difficulties performing everyday tasks that require executive function (e.g. planning, monitoring behavior, and controlling emotions) (Isquith et al., 2006; Roth, Isquith & Gioia, 2005).

Objective measures of cognitive and motor performance are often utilized to quantify the influence of sleep disruption and fatigue on a variety of mental processes (Neu et al., 2011; Pilcher & Huffcutt, 1996); however, Durmer and Dinges (2005) note that some tasks are more sensitive to the effects of sleep deprivation than others. For instance, overly complicated or trivial tasks of no interest to the participant are insensitive to the effects of sleep loss (Dorrian, Rogers, & Dinges, 2005; Durmer & Dinges, 2005). Also, tasks that require a certain aptitude or that are susceptible to practice effects may result in discrepancies, confounding the true extent in which sleep loss affects cognition (Lamond et al., 2008). As a result, measures of performance need to be reliable and valid, resistant to learning effects, and sensitive to sleep loss in order to obtain valid results (Dorrian, Rogers, & Dinges, 2005; Durmer & Dinges, 2005).

An example of an effective task for measuring cognitive and motor performance is the psychomotor vigilance test (PVT). The PVT is a sustained-vigilance task that measures response times (in milliseconds) to visual stimuli that are presented at random inter-stimulus intervals (ISIs) (Dinges & Powell, 1985; Thorne et al., 2005; Van Dongen & Dinges, 2005). Attention, or vigilance, is a quantifiable characteristic of executive function considered to be one of the most reliable measures of ongoing neurobehavioural function and performance (Dorrian, Rogers, & Dinges, 2005; Durmer & Dinges, 2005). The PVT requires continuous attention in order for the participant to quickly and accurately respond to the randomly occurring stimuli (Tucker at al., 2009). Typically the PVT is 10 minutes in duration; however, previous research has shown that a shorter version of the PVT limits participant burden, remains sensitive to the effects of sleep deprivation, and is more practical in an applied context (Basner, Mollicone, & Dinges, 2011; Neylan et al., 2010; Roach, Dawson, & Lamond, 2006; Thorne et al., 2005).

The PVT is sensitive to sleep loss, sleep pathology, circadian disruption, and the associated experience of subjective fatigue (Balkin et al., 2004; Basner & Dinges, 2011; Dinges & Powell, 1985; Dorrian, Rogers, & Dinges, 2005; Philip et al., 2012; Van Dongen et al., 2003). In addition, declines in executive functions such as psychomotor performance (Epstein et al., 1980) and vigilance (for a review see, Hancock & Vasmatzidis, 2003) have also been found in those exposed to elevated temperatures. Metrics obtained from the PVT include reaction time (RT), response speed (RT^{-1}), number of lapses in attention (RTs greater than 355 msec), and errors of commission, also referred to as “false starts” or “jumping the gun”. Although not a direct measure of fatigue the variables assayed by the PVT, reaction time (Balkin et al., 2004) and number of lapses (Lee et al., 2010), can be used to objectively quantify the effect of fatigue on cognition.

The PVT has been validated repeatedly in both field and laboratory-based studies (Drummond et al., 2005; Killgore et al., 2009; Van Dongen et al., 2003). In field studies, several populations have been assessed using the PVT including nurses (Ruggiero et al., 2012), physicians (Gander et al., 2008), commercial airline pilots (Petrilli et al., 2006), miners (Ferguson et al., 2011), and commercial truck drivers (Pack et al., 2006). Several studies investigating the effects of sleep loss have also utilized the PVT in conjunction with other assays sensitive to fatigue, such as driving simulators (Baulk et al., 2008) and subjective fatigue scales including the Multidimensional Fatigue Inventory (Lee et al., 2010). The PVT accommodates all levels of aptitude and is ideal for repeated use due to its negligible learning effects (Whitmire et al., 2009). Furthermore, the PVT has recently been adapted for use on touch-screen devices, such as smart phones, to increase practicality and availability (Kay et al., 2013). Although a very simple task, the PVT is considered the gold-standard method for assessing the changes in attentional processes brought on by sleep deprivation (Franzen, Siegle, & Buysse, 2008; Tucker et al., 2009).

Decreases in attentional capacity due to inadequate sleep, or other fatigue-inducing factors, can influence the productivity and safety of workers (Nicholls, Bren & Humphreys, 2004). Many workers, including underground miners, experience hazardous environments where a lapse in attention could quickly put themselves at risk of injury or death (Legault, 2011). For workers these attentional lapses may be due to workplace distractions (noise, lighting, other workers) and/or the experience of fatigue (Streff & Spradlin, 2000; Valdez, Reilly, & Waterhouse, 2008). Accordingly, higher incidences of accidents and injuries of greater severity are reported in vocations where fatigue-inducing factors are prevalent (Rosa, 1995; Wagner, 1988). In addition, some occupations have individuals whose workplace fatigue may present a risk to not only themselves but to others (e.g. miners, physicians, pilots, truck drivers, and soldiers) (Caldwell, 2012; Johnson, 2007; Pandi-Perumal et al., 2006; Rothschild et al., 2009). In order to prevent occupational injury and illness it is important to understand to what extent fatigue affects workers, what factors can cause fatigue, and how fatigue can be ameliorated in the workplace.

1.3 Causes and Consequences of Fatigue in the Workplace

The influence of fatigue during work hours may be a result of a shortened sleep periods due to shift work (Åkerstedt, 2003; Åkerstedt et al., 2002b) or underlying sleep pathology (Hossain et al., 2003). Other factors can include disturbed circadian rhythms (Arendt, 2010), time of day (Dorrian, Hussey, & Dawson, 2007), extended work hours and increased time spent awake (Berryman, Lukes, & Keller, 2009; Rosa, 1995), monotonous work tasks (McPhee, 2004; Sallinen et al., 2004), or even the work environment itself (i.e. elevated ambient temperatures) (Hancock & Vasmatzidis, 2003; Jay & Kenny, 2010).The combined effects of multiple fatigue-inducing factors can leave a worker with cognitive impairment (Ferguson et al., 2011; Shen et al., 2006). Fatigue resulting from sleep deprivation and poor sleep quality is especially prevalent in individuals who work irregular schedules or “shift workers” (Barger et al., 2006; Dinges, 1995). As a result, fatigued workers who are performing at less than peak levels of performance may lead to an increase in the possibility of experiencing workplace accidents (Dinges, 1995; Halvani, Zare, & Mirmohammadi, 2009).

1.3.1 Shift Work

In a society demanding that services and resources be available around the clock, having workers engaged in shift work is inescapable. In 2005 approximately 4.1 million Canadians, 28% of the work force, were employed as shift workers (Williams, 2008). Shift work can include; evening shifts, night shifts, split shifts, on-call or casual shifts, irregular shifts, and rotating shifts (Williams, 2008). To capture the wide range of observed shift work schedules, the National Sleep Foundation (n.d.) proposed that ‘shift work’ be defined as any work schedule that falls outside of the typical 9 A.M. to 5 P.M. business day. Although extended daytime shifts (those lasting longer than 8 hours) and compressed work weeks are often not classified as shift work, they fall into the shift work category based on the above criteria (Berryman, Lukes, & Keller, 2009). Shift work schedules are commonly implemented in the health and protective services (law enforcement and fire service), the hospitality industry, and industries such as logging and mining (Williams, 2005).

Shift work schedules commonly lead to an inadequate amount and poor quality of sleep for workers prior to beginning their shifts (Åkerstedt, 2003, 2013; Flo et al., 2013; Legault, 2012). Due to their irregular work schedules, night shift workers sleep an average of 2 hours less per 24 hours than non-shift workers (Hui et al., 2011; Kloss et al., 2002; Pilcher, Lambert, & Huffcutt, 2000; Tilley et al., 1982). Consequently, these workers usually obtain only 4 to 6 hours of sleep prior to beginning a shift (Åkerstedt, 2003), much less than the 8 hours recommended for maintaining cognitive functions such as alertness (Van Dongen et al., 2003). As a consequence of this sleep deprivation, nearly 70% of individuals who work shift schedules report experiencing excessive daytime sleepiness, increasing their risk of falling asleep at inappropriate times (Åkerstedt & Torsvall, 1981; Kloss et al., 2002). Unsurprisingly, those who engage in shift work experience greater levels of daytime fatigue and increased numbers of attentional lapses compared to their non-shift working counterparts (Shen et al., 2006). The increased presence of fatigue in shift workers can result in a greater risk of experiencing occupational accidents and injuries (Dinges, 1995; Halvani, Zare, & Mirmohammadi, 2009; Frank, 2000).

The degree of subjective fatigue reported by workers is significantly correlated to the frequency in which they engage in shift work (Shen et al., 2006). Hossain and colleagues (2003) found that subjective sleepiness and subjective fatigue were weakly correlated in a sample of underground miners who often worked irregular shifts. Nearly three-quarters (71.4%) of the highly fatigued participants in this study also demonstrated an underlying sleep pathology (obstructive sleep apnea, periodic limb movement disorder, and bruxism) (Hossain et al., 2003). In addition, Halvani, Zare, and Mirmohammadi (2009) found that subjective fatigue, and not subjective sleepiness, was significantly elevated in industrial workers involved in shiftwork (working outside the hours of 07:00 – 18:00) compared to a non-shiftworking sample. These authors also reported that increased subjective fatigue in the shift working sample was significantly correlated with experiencing an occupational accident, a result not found in the non-shift workers.

The sleep deprivation and fatigue that is characteristic of these workers can be a consequence of shortened sleep periods (sleep quantity) or disturbed sleep (sleep quality). Work-related obligations often reduce sleep time due to imposed schedules or deadlines, especially in the case of shift work schedules and when completing numerous lengthy shifts in succession. Day shifts, especially those with start times before 07:00, often lead to severe sleep truncation (Åkerstedt, 2003; Flo et al., 2013). This sleep loss is typically because workers are unable to advance bedtimes in order to compensate for early wake times due to domestic responsibilities and social obligations (Åkerstedt et al., 2002b; Flo et al., 2013). In addition, many adult workers are unable to initiate sleep in the early evening when physiological "wakefulness" is near its peak, further impeding bedtimes well into the late evening (Jenni & Carskadon, 2009). For individuals with lengthy commutes to the workplace, wake times are even earlier resulting in further reductions to sleep time and longer work days. Similarly, night workers also contend with shortened sleep periods and lengthy commutes causing fatigue during work times.

Daytime sleep that occurs after night shifts is of a shorter duration, prone to disruption, and is easily terminated (Åkerstedt, 2003; Flo et al., 2013; Hui et al., 2003). Disruptions to a sleep period, or awakenings, decrease the proportion of time spent sleeping in relation to the time spent in bed, a measure of sleep quality referred to as sleep efficiency (SE) (Guilleminault & Brooks, 2001). The ambient light and environmental noises that accompany daylight hours likely exacerbate the reduced SE obtained by shift workers during daytime sleep periods (Lamond et al., 2003). These disruptions to sleep and other biological cycles are characteristic of atypical schedules and likely mediate the relationship between shift work and several health concerns (Arendt, 2010; Banks & Dinges, 2007; Flo et al., 2013; Haus & Smolensky, 2006; Knutsson, 2003).

1.3.1.1 Health concerns associated with shift work

Previous research has showed that shift work is associated with several health concerns. Diabetes (Knutson & Van Cauter, 2008), cardiovascular disease (Kawachi et al., 1995; Leclerc, 2010), obesity (Di Milia & Mummery, 2009), and gastrointestinal disorders (Nojkov et al., 2010) are just a few of the physical health problems that have been linked to shift work. Cancer is also prevalent in shift workers (Costa et al., 2010). The International Agency for Research on Cancer has deemed shift work as a probable carcinogen (Stevens et al., 2011).

Mental health issues are also a matter of concern for shift workers due to the increases in stress and decreases in quality of life associated with working irregular schedules (Colligan & Rosa, 1990; Shields, 2002; Shao et al., 2010). Previous studies have suggested that sleep loss and fatigue have detrimental effects on mood and that mood is more sensitive to the effects of sleep disturbance than either cognitive or motor performance (Pilcher & Huffcutt, 1996). Disrupted sleep and the consequent fatigue experienced by workers can result in increased negative mood, feelings of somnolence, loss of vigor, and confusion (Durmer & Dinges, 2005). Inadequate sleep and prolonged wakefulness are also blamed for feelings of increased irritability, anxiety, and depression, mood states typically seen in sleep disorders (Durmer & Dinges, 2005). In addition, individuals may become more prone to disordered thinking (hallucinations, delusions, suicidal ideation) and more susceptible to mental illnesses or find already existing mental conditions intensified after experiencing disrupted sleep or extended wakefulness (Hossain et al., 2005; Kloss et al., 2002). These alterations in mood can leave individuals becoming more introverted, less motivated, and living with a reduced quality of life (Shao et al., 2010). Furthermore, the mental fatigue and other cognitive consequences experienced due to sleep loss can lead to decreased performance and increased likeliness of accidents (Dinges, 1995).

Workers who face any of these health concerns are more likely to exhibit decreases in productivity and success, increases in absenteeism and apathy, and also elevations in fatigue levels (Shen et al., 2006). These consequences are not only concerns for workers but also for their employers. The fatigue experienced by shift workers may cause risks to health and well-being in the form of occupational accidents which could potentially result in stress, injury, lost time from work, or even death (Dinges, 1995).

1.3.2 Circadian Rhythm Disruption

Work schedules that combine both day and night shifts are commonly referred to as rotating shift schedules. These rotational schedules are especially disruptive to normal biological rhythms and the physiological processes they mediate (Barger et al., 2006; Costa, 2003; Haus & Smolensky, 2006). Circadian rhythms are endogenous biological cycles that regulate a variety of physiological processes according to an approximate 24-hour interval (Panda, Hogenesch, & Kay, 2002). This rhythm is driven by endogenous and exogenous cues, or zeitgebers, primarily the light/dark cycle but also social interactions and eating patterns (Edery, 2000; Kyriacou & Hastings, 2010). Some of the biological processes influenced by circadian rhythms include sleep/wake cycles, core body temperature, metabolism, hormone secretion (cortisol, melatonin, growth hormone), and cognitive processes including attention (Arendt, 2010; Edery, 2000; Van Dongen and Dinges, 2005; Whitmire et al., 2009).

For many of these physiological processes their maximum activity has a peak, or acrophase, in the daily circadian cycle. Several of these circadian-patterned responses exhibit a peak in activity during the late afternoon and early evening hours (Schmidt et al., 2012). Conversely, the lowest levels of physiological activity take place during the circadian trough, or nadir, typically experienced in the early morning hours (Schmidt et al., 2012). In healthy individuals, sleep onset usually occurs as physiological activity declines towards the circadian nadir. During these low levels of physiological activity individuals are also prone to increases in subjective fatigue, performance variability, attentional lapses, and decreases in cognitive performance (Blatter & Cajochen, 2007; Killgore et al., 2009). Accordingly, when imposed work schedules encompass the circadian nadir workers may be at increased risk for occupational accidents and injuries (Arendt, 2010; Folkard & Tucker, 2003; Mustard et al., 2012; Wagner, 1988; Wong, McLeod, & Demers, 2011). For instance, during night shifts the risk of personal injury for police officers was significantly higher compared to day and afternoon shifts (Violanti et al., 2012). Also, nighttime mining accidents were significantly more severe, resulting in a greater number of lost-time days for workers, than accidents that took place during the day or afternoon (Wagner, 1988). However, the circadian rhythm is only one of two processes responsible for regulating the human sleep/wake cycle.

Circadian rhythms interact with the homeostatic sleep drive, also referred to as sleep pressure, in order to determine the timing of sleep onset and offset (Achermann, 2004; Jenni & Carskadon, 2009; Schmidt et al., 2007). Sleep pressure is the physiological need for sleep that increases with continued wakefulness (Flo et al., 2013; Jenni & Carskadon, 2009; Schmidt et al., 2007). This homeostatic sleep drive is regulated by the inhibitory neurotransmitter adenosine (Blanco-Centurion et al., 2006; Zepelin, 2000). As a by-product of cellular metabolism, concentrations of extracellular adenosine increase throughout wakefulness when neuronal energy demands are high (Zeitzer, 2009). While adenosine accumulates it begins to inhibit the activity of wake-inducing neurons located in subcortical brain regions, specifically the basal forebrain including the nucleus accumbens, substantia innominate, and the diagonal band of Broca), which subsequently promotes sleep onset (McCarly, 2007; Zeitzer, 2009; Zeitzer et al., 2006). Sleep pressure will continue to accrue until sleep onset occurs (Blanco-Centurion et al., 2006; Zepelin, 2000). In contrast, the concentration of adenosine diminishes during sleep, alleviating sleep pressure and facilitating sleep offset (wakefulness) (Blanco-Centurion et al., 2006).

These daily fluctuations in circadian rhythms and sleep pressure are the basis of Borbély's (1982) model of sleep regulation. This 'two-process model' proposes that the circadian process (Process C) and the sleep homeostatic process (Process S) interact to determine the daily temporal patterns of sleep and wakefulness (Figure 1) (Beersma, 1998; Borbély, 1982;

Daan, Beersma, & Borbély, 1984). The two-process model predicts that when circadian activity is low (Process C) and sleep pressure is high (Process S), typical of late evening hours, the two processes are in opposition and sleep onset is facilitated. Once sleep is achieved, circadian activity continues to approach its nadir, counteracting the decline in sleep pressure and ensuring the maintenance of sleep (Schmidt et al., 2007). Alternatively, during the morning hours, the Process C mediated drive is high and Process S drive is low, resulting in individuals being awake and alert. As the day progresses, sleep pressure accumulates during wakefulness and is countered by the parallel increase in physiological activity (Schmidt et al., 2007). In the event these processes become desynchronized due to shift work, difficulties initiating and maintaining sleep as well as excessive daytime fatigue and wake-state instability, are experienced (Arendt, 2010; Haus & Smolensky, 2006; Rajaratnam & Arendt, 2001).

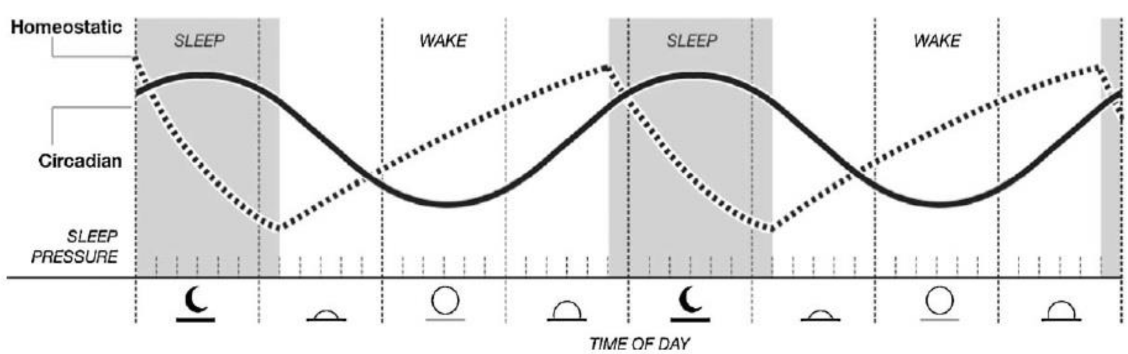


Figure 1. Two-process model of sleep regulation including homeostatic and circadian processes. Reprinted from "Circadian rhythms and sleep in children with autism," by G. Glickman, 2010, *Neuroscience and Biobehavioral Reviews*, *34*, p. 756. Copyright by Elsevier. Reprinted with permission.

The dysregulated circadian rhythms experienced by those working shifts often result in shift work sleep disorder, a subtype of circadian rhythm sleep disorder (CRSD). The

International Classification of Sleep Disorders-2 (ICSD-2) classifies CRSDs as dyssomnias, disorders marked by a complaint of insomnia or excessive sleepiness (AASM, 2005). In the case of shift work sleep disorder, the experience of insomnia and/or excessive sleepiness arises from sleep difficulties characteristic of an extrinsic source: irregular shift schedules (AASM, 2005). Individuals working night shifts struggle with maintaining sleep (experiencing bouts of wakefulness during sleep times and waking before intended) resulting in shortened sleep periods of reduced sleep quality (AASM, 2005; Åkerstedt, 2003; Flo et al., 2013). Difficulty initiating sleep and subsequently terminating sleep are the primary complaint of those who work early morning shifts, leaving these workers feeling unrested following sleep (AASM, 2005; Åkerstedt, 2003; Flo et al., 2013)). These symptoms typically follow the course of the shift schedule and although improvement in symptoms may occur after the first week of a new shift, complete disappearance of symptoms is rare (AASM, 2005).

Shift workers waking up at pre-dawn hours struggle to terminate sleep, resulting in less than optimal cognitive performance in the early morning hours and sleepiness lasting throughout the day. Åkerstedt (2003) refers to this specific phenomenon as "circadian interference," a consequence of wake times coinciding with the circadian nadir. In addition, fatigue is especially prevalent throughout night time shifts when workers are forced to remain alert and active during the circadian trough (Åkerstedt, 1995). The Diagnostic and Statistical Manual of Mental Disorders-V (DSM-V) also recognizes 'shift work type' CRSD as a distinct diagnosis and suggests that it may affect up to 10% of night and rotating shift workers (American Psychiatric Association, 2013; Drake et al., 2004).

The combination of fatigue and desynchronized circadian rhythms in shift workers results in cognitive deficits including lapses in behaviour (i.e. attention and memory) as well as microsleeps while on the job (Barger et al., 2006; Dinges & Banks, 2009; Durmer & Dinges, 2005). Further consequences of shift work sleep disorder include increased irritability, difficulties maintaining social relationships, and reduced alertness and performance (Åkerstedt, 2003; Costa, 2003; ICSD-2, 2005). These negative side effects of circadian rhythm disruption likely contribute to the increased risk for occupational injuries and accidents experienced by rotational shift workers when compared to those working fixed schedules (Ott et al., 2009; Salminen, 2010; Wagstaff & Sigstad Lie, 2011). In addition, disrupted sleep and circadian rhythms leave individuals more susceptible to illnesses (physical and mental), and can aggravate the symptoms of pre-existing conditions (Hossain et al., 2005). As a result, the reciprocal relationship between sleep and circadian disturbances likely exacerbates the already negative effects that fatigue has on the health and daily functioning of workers (Ball & Evans, 2001).

1.3.3 Consecutive Shifts

The insufficient amount and poor quality of sleep that workers acquire across consecutive shifts often leads to an accumulation of physiological sleep debt (Lamond et al., 2003). Theoretically, sleep debt can be determined by subtracting the amount of sleep attained by an individual from the amount of sleep that they require (Williams, 2001). Sleep debt will continue to accrue as long as physiological sleep requirements remain unfulfilled, which can result from both acute and chronic sleep loss (Belenky et al., 2003). The frequency and duration of sleep loss interact with one another and determine the severity of sleep debt, whether moderate or extreme. For example, multiple nights of moderate sleep restriction (inadequate sleep quality or duration), like that experienced by shift workers, could be as detrimental to cognitive performance as an evening of total sleep deprivation (Banks & Dinges, 2007; Belenky et al., 2003; Drake et al., 2001; Philip et al., 2012; Van Dongen et al., 2003).

Consecutive work shifts result in chronic sleep restriction and leave little opportunity for recovery sleep, in turn leading to increased sleep debt and compounding fatigue levels. This type of sleep loss is particularly problematic for those bound by shift work schedules (Åkerstedt, 1990, 2003; Banks & Dinges, 2007) as well as those who work extended shifts (Berryman, Lukes, & Keller, 2009). According to reviews completed by Folkard and Lombardi (2006) and Salminen (2010), the risk of occupational injury in workers steadily increases with each successive shift worked. For example, those working night shifts were 6% more likely to experience an occupational injury during their second consecutive night shift, a risk that increased to 36% by their fourth consecutive night shift (Salminen, 2010). A similar trend was found for those working morning shifts; workers on their second and fourth successive morning shifts experienced a 2% and 17% increase in risk, respectively (Salminen, 2010).

In addition, Shen and colleagues (2006) reported that the number of shifts worked in a week had a significant and positive correlation with the subjective experience of fatigue. For example, after working five consecutive night shifts, police officers experienced significantly more attentional lapses and elevated levels of subjective sleepiness compared to days off (Waggoner et al., 2012). Increases in subjective fatigue and other manifestations of excessive tiredness are detrimental to cognition and increase the likelihood of human error, especially during early morning hours (Åkertstedt, 1995; Dinges, 1995; Harrington, 2001). Maybe not surprisingly, fatigue and human error among shift workers has been linked to major disasters such as the Three Mile Island nuclear power plant incident, the Exxon Valdez oil spill, the Challenger Space Shuttle explosion, and the nuclear accident at Chernobyl (Folkard & Tucker, 2003; Milter et al., 1998). Furthermore, all of these catastrophes occurred in the early morning (Folkard & Lombardi, 2006). The combination of inadequate sleep prior to work times and prolonged periods of wakefulness experienced by these workers may have contributed to the cause of these tragedies (Dinges, 1995).

1.3.4 Extended Wake Time

Extended wakefulness creates an additional fatigue-inducing factor for individuals who follow shift work schedules, especially those working nights or extended shifts (Barger et al., 2006; Baulk et al., 2009). Due to the homeostatic sleep process (Process S) being mediated by the duration of time an individual spends awake, any extended periods of wake time can result in increased sleep pressure as well as the associated consequences (decreased cognitive performance and increased fatigue). Previous research has shown that the cumulative time spent awake prior to and throughout a shift has a significant effect on the level of sleepiness (Chang et al., 2013) and fatigue a worker may be experiencing (Baulk et al., 2008; Baulk et al., 2009; Van Dongen et al., 2003), as well as their attention, memory, and mood (Dinges & Banks, 2009). Van Dongen and colleagues (2003) suggested that cumulative wake time was a better predictor of performance on cognitive tasks (vigilance, working memory, and cognitive throughput) than the amount of sleep obtained in the preceding 24 hours. Cumulative wakefulness in excess of 16 hours (approximately) resulted in a nearly linear increase in behavioural lapses during a vigilance task (Van Dongen et al., 2003) and an increased risk of adverse driving events during post-shift commutes (Ftouni et al., 2013). When observed in an occupational context the consequences of prolonged wakefulness have been unfavorable.

Several studies have reported that longer work hours are associated with a cumulative increase in occupational accidents and injuries (Dembe et al., 2005; Dong, 2005; Folkard & Lombardi, 2006; Hänecke et al., 1998; Rosa, 1995; Vegso, Cantley, & Slade, 2007; Wagstaff & Sigstad Lie, 2011). A clear dose-response curve was established when Dembe and colleagues

(2005) investigated the frequency of incidents experienced by workers in relation to the number of hours they worked per day (or week). For example, workplace accidents and injuries are purportedly three times more likely to occur after 16 consecutive hours of work compared to accident rates after nine consecutive work hours (Åkerstedt, 1994; Rosa, 1995). After working12 hours on the job the risk of experiencing a workplace accident is double that of an eight-hour shift (Wagstaff & Sigstad lie, 2011). Similarly, extending the work day as little as two hours, from an eight-hour work shift to a 10-hour shift, appears to increase the likelihood of workers experiencing an occupational injury by 41% (Salminen, 2010).

It is important to note that fatigued employees are a potential threat to not only themselves but others as well. In a study following critical care nurses, researchers found that after 12.5 hours on the job nurses were twice as likely to make an adverse occupational error (e.g. medication administration, procedural, or charting) affecting a patient (Scott et al., 2006). Similarly, first year medical residents were four times more likely to make a fatal, fatigue-related medical error if they worked five or more extended-duration shifts (shifts exceeding 24 consecutive hours) in a month (Barger et al., 2006). Military pilots who spent 27 consecutive hours awake displayed significantly impaired performance in basic flight skills and a 60-100% increase in inaccurate responses to warning signals (Caldwell et al., 2004). Finally, extended wakefulness may also be deadly for drivers: after 12 consecutive hours of driving, transport drivers are twice as likely to be involved in a motor vehicle accident compared to the risk after eight hours of driving (Folkard, 1997 & 2003).

Drowsy driving is associated with behavioural lapses, prolonged eye closures, microsleeps, and reduced response time to stimuli, which stem from increased levels of fatigue (Ftouni et al., 2013; Kloss et al., 2002; Moller et al., 2006). Scott and colleagues (2007) have reported that the risk of experiencing an episode of drowsy driving doubles for nurses after working 12.5 or more consecutive hours. In a more recent study of shift-working nurses, the risk of experiencing an adverse driving event was four times more likely after participants spent 16 hours or more awake (Ftouni et al., 2013). In addition, the motor and cognitive performance of individuals after a night without sleep is comparable to those with a blood alcohol level (BAC) of 0.07% and decreases as wake time is prolonged (Fairclough & Graham, 1999). After approximately 28 hours of wakefulness an individual's driving performance is equivalent to having a BAC of 0.10%, 0.02% higher than the legal limit in Canada (Lamond et al., 2004; Williamson & Feyer, 2000). Consequently, workers are much more likely to be involved in traffic accidents when driving home after a night shift (Ftouni et al., 2013; Lyznicki et al., 1998; Scott et al., 2007).

Moller (2008) noted that 20% of Canadians - 4 million people - admitted to nodding off or falling asleep at the wheel at least once in the previous year. Accordingly, driver fatigue is the primary contributor in the death of roughly 400 Canadians every year (Moller, 2008). As a result, fatigue is responsible for approximately 1.4% of fatal motor vehicle accidents (MVAs), comparable to the 2.1% caused by drunk drivers (Kloss et al., 2002). Similar to those under the influence of alcohol, fatigued individuals report only moderate feelings of subjective sleepiness despite demonstrating significantly impaired performance on objective measures (Philip et al., 2012; Zhou et al., 2012). Seemingly, the decline in cognitive performance associated with extended periods of wakefulness can increase the potential for human error and fatigue-related accidents while working or commuting.

Whether the result of sleep deprivation, circadian rhythm disruption, or prolonged time spent awake, the accumulation of fatigue in workers can be detrimental. Unfortunately, for many individuals, the source of these fatigue-inducing factors is their own work schedule. Individuals bound to shift work and extended durations shifts are especially susceptible to sleep deprivation and circadian rhythm disruption; primary contributors to the manifestation of fatigue in workers. As mentioned previously, individuals who engage in shift work are prone to developing difficulties initiating or maintaining sleep due to circadian rhythm disruption. On the other hand, workers who are involved in extended duration shifts have less time to spend in bed and are awake for longer durations resulting in shortened sleep periods. Given that the majority of workers also complete multiple consecutive shifts, sleep deprivation and fatigue may accrue with little reprieve.

When rotating shift schedules are combined with extended duration shifts, workers must contend with truncated time available for sleep, fragmented sleep periods, and dysregulated circadian rhythms. Any of these factors can affect sleep negatively and result in difficulties obtaining sufficient sleep. Both acute and chronic sleep loss can elicit fatigue in workers, resulting in dangerous cognitive and behavioural consequences. By quantifying sleep behaviours (e.g. timing of sleep, sleep duration, and sleep quality) the relationship between work schedules, sleep deprivation, disrupted circadian rhythms, and fatigue may be elucidated. Many tools have been developed for this purpose.

1.3.5 Evaluating Sleep and Circadian Disruption

In order to determine the extent of an individual's sleep and circadian disruption, and their subsequent SE, objective and subjective measures of sleep and circadian activity are often utilized by researchers. Objective tools used to determine SE include polysomnography (PSG) and actigraphy. Considered the gold-standard method in the assessment of sleep behaviours, a PSG combines the use of multiple physiological measures in a laboratory setting to determine sleep and wake physiology (Vaughn & Giallanza, 2008). A standard polysomnograph will utilize EEG, EOG, and EMG (electromyography) measures. More elaborate studies will sometimes include additional measures such as heart and/or respiration rate. The combined application of these instruments provides an accurate assessment of sleep stage and wake activity that can be used to diagnose sleep pathology (Vaughn & Giallanza, 2008). Due to the clinical nature of PSGs these studies are done in a laboratory by trained individuals and are not amenable to field studies.

Actigraphy is a non-invasive technique used to objectively quantify sleep quality, sleep duration, and circadian disruption. Actigraphy records the onset and duration of sleep and wake cycles based on the gross motor movement of the individual being assessed (de Souza et al., 2003). Movement is measured using a small device worn on a limb such as the wrist or ankle. A piezoelectric sensor within the actigraph measures force and acceleration (movement) in any direction (Ancoli-Israel et al., 2003). Actigraphy has been used extensively in the study of sleep and circadian rhythms (Ancoli-Israel et al., 2003, Morgenthaler et al., 2007).

Although not as exhaustive in its measurements, previous studies have shown that sleep behaviour measured with actigraphy correlated with data obtained using polysomnographic studies (de Souza et al., 2003; Kushida et al., 2001; Tonetti et al., 2008). Variables measured in actigraphy include sleep onset latency (SOL), total time spent in bed (TIB), total time spent sleeping (TST), wake time after sleep onset (WASO), and SE. Although actigraphy measures many of the same sleep behaviours as PSG, this tool is not yet able to identify specific sleep stages. In addition, actigraphy is inferior to PSG when determining SOL and waking epochs during sleep (de Souza, 2003; McCall & McCall, 2012). Inaccurate measures of these sleep behaviours may skew measures of sleep efficiency. That aside, previous research indicates that sleep data obtained through the combination of actigraphy and subjective reports, such as a sleep log, does not differ significantly from measures reported by PSG (Kushida et al., 2001). Despite these shortcomings, actigraphy has one major advantage over polysomnography: actigraphy can conveniently record data continuously for days or weeks at a time (Ancoli-Israel et al., 2003). For this reason actigraphy is far more appropriate for longitudinal field studies and those studies investigating sleep patterns and circadian rhythms over an extended period of time.

When unaccompanied by objective measures, subjective reports of sleep behaviours are often poor indicators of sleep behaviour, especially in clinical populations (McCall and McCall, 2012). However, subjective measures are a useful supplement to objective measures such as PSG or actigraphy (Kushida et al., 2001). One of the most commonly used measures of subjective sleep quality is the Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) (Durmer & Dinges, 2005). The PSQI has been paired with objective measures (PSG and actigraphy) of sleep behaviours, as well as subjective measures such as sleep logs, in both healthy and clinical samples (Beaudreau et al., 2012; Grandner et al., 2006). In a healthy population, the data obtained from the PSQI was significantly correlated with information gathered from sleep logs (Grandner et al., 2006).This questionnaire uses seven scales (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction) in order to estimate an individual’s sleep quality. A global score on the PSQI of 5 or greater indicates a “poor” sleeper, defined as someone who has poor overall sleep quality (Buysse et al., 1989; Knutson et al., 2006). The PSQI consistently distinguishes “good sleepers” from “bad sleepers” in a healthy population and can also identify maladaptive sleep behaviours (Buysse et al., 1989); however, the PSQI is not considered as a diagnostic tool.

1.3.6 Heat Exposure

When the human body is placed under an increased net heat load (heat stress) the body's physiological and behavioural response is referred to as heat strain (American Conference of Governmental Industrial Hygienists [ACGIH], 2011). Individuals working under conditions that induce heat strain will eventually develop fatigue and potentially dehydration (Jay & Kenny, 2010; Leveritt, 1998; Polkinghorne et al., 2013). Other consequences of heat strain include degraded cognitive performance (decreased attention, vigilance, and problem-solving ability) as well as irritability (anger and poor emotional control) (Hancock & Vasmatzidis, 2003; Leveritt, 1998; Lucas, Epstein, & Kjellstrom, 2014; Raymann & Van Someren, 2007). The deleterious effects of heat strain influence mental and physical activities, leading to reduced productivity and increased potential for human-related errors in workers (Brake & Bates, 2001; Lucas, Epstein, & Kjellstrom, 2014; Misaqi et al., 1976; Radakovic et al., 2007). Furthermore, prolonged heat exposure and hypohydration may also result in heat disorders such as heat cramps, heat exhaustion, and heat stroke; heat stroke being the most severe, and sometimes fatal, of these heat disorders (Hunt, 2011; Hunt, Parker, & Stewart, 2014; Lahey, 1984; Misaqi et al., 1976). Accordingly, the degree of heat strain an individual experiences is dictated by the amount of heat stress they endure (Varley, 2004).

Both internal (physiological) and external (environmental) factors influence the degree of heat stress an individual may experience (Leveritt, 1998). Examples of internal heat factors include core body temperature (CBT), metabolic heat production, natural heat tolerance, and acclimatization (Lahey, 1984; Leveritt, 1998). Metabolic heat production is a temporary process, fluctuating as a function of work load (i.e. increasing as the level of physical activity becomes more strenuous) (Hardcastle, Reardon, Kenny, & Allen, 2009; Kenny et al., 2012). In contrast, acclimatization is the physiological adaptation of the body to environmental stressors resulting in an increased tolerance to heat stress and, subsequently, reduced heat strain (Cheung & McLellan, 1998; Hunt, 2011; Radakovic et al., 2007). Approximately 7-14 days of repeated exposure to the external heat source is required for acclimatization to take place (Armstrong & Maresh, 1991), however acclimatization will reverse if exposure to the stressor does not continue. Consequently, internal heat factors regulate how an individual will react to external heat stressors such as working in elevated temperatures.

Common environmental sources which precipitate heat strain are pervasive in underground mining environments (Brake & Bates, 2001; Cho & Lee, 1978; Leveritt, 1998; Kalkowsky & Kampmann; 2006; Varley, 2004). Some sources of external heat (environmental stressors) include ambient air temperature, air movement (wind speed), humidity, and rock temperature (Lahey, 1984; Payne & Mitra, 2008). Other factors in an underground mine that contribute to increased ambient air temperatures include the workers themselves, autocompression (compressed air moved through ventilation systems), ground water, mechanical processes (e.g. diesel powered equipment and electrical units), and rock movement (e.g. blasting) (Cho & Lee, 1978; Kenny et al., 2009; Payne & Mitra, 2008; Piekarski, 1995). Additionally, the terrestrial heat in an underground mining environment increases with depth following a geothermal gradient, raising in temperature approximately 2.5-3.0°C per every 100m below surface level (Donoghue, Sinclair, & Bates, 2000; Payne & Mitra, 2008). Measurements of external heat sources, including air temperature, air movement, and humidity, are typically integrated in order to determine heat indices such as the wet bulb globe temperature (WBGT) (ACGIH, 2011; Kjellstrom, Holmer, & Lemke, 2009).

The WBGT is a common environmental index utilized by the Canadian mining industry to assess levels of heat stress experienced by workers (Kenny et al., 2009). A WBGT is determined based on measures of air temperature (dry bulb temperature; T_{db}), humidity and air velocity (wet bulb temperature; T_{wb}), and also radiant temperature (globe temperature; T_g), determined using a globe thermometer (Kjellstrom, Holmer, & Lemke, 2009). By using WBGT indices the ACGIH has developed standardized heat stress screening criteria and threshold limit values (TLVs) to help minimize the risk of heat stress-related symptoms and illnesses in workers (ACGIH, 2011). TLVs specify the level of a physical agent (e.g. heat stress) to which nearly all workers can be repeatedly exposed to without experiencing adverse effects. In order to establish best practices for preserving worker health and safety in hot environments, the ACGIH provides recommendations based on an environment's WBGT as well as a worker's ongoing work demands and clothing/personal protective equipment (PPE) requirements (ACGIH, 2011). For example, the ACGIH Screening Criteria for Heat Stress Exposure suggests that an acclimatized individual completing a heavy work load (strenuous) in a WBGT exceeding 28°C is at an increased risk for heat injury and should implement heat management strategies. These strategies may include taking precautions to stay well hydrated, reducing their level of activity, and/or taking several rest breaks.

Although heat management strategies alleviate the heat stress placed on a worker, excess heat needs to be dissipated from the body in order for individuals to maintain physiological thermal balance. If the heat being generated in the body is greater than the heat lost, heat accumulation will occur and CBT will increase. Once an individual's CBT surpasses 40°C decreases in cognitive performance and heat stroke are imminent (Donoghue, Sinclair, & Bates, 2000; Leveritt, 1998; Strang & Mackenzie-Wood, 1990). The means by which internal heat is able to exit the body is through conduction, when the skin is contact with cooler air; convection, when air is circulated; radiative heat exchange to cooler areas not in contact with the skin; and evaporation of sweat and water from the skin (Leveritt, 1998; Payne & Mitra, 2008). Heat convection and radiation account for the majority of the body's heat dissipation and are primarily mediated by surrounding environmental conditions (e.g. ambient air temperature and air velocity). However, convection and radiation methods of heat dissipation remain fairly constant and do not increase in response to the metabolic heat production that occurs during physical activity (Leveritt, 1998). Consequently, to maintain thermal balance and alleviate the additional heat generated during physical activity (metabolic heat), heat dissipation through sweat evaporation must increase (Leveritt, 1998; Misaqi et al., 1976). Furthermore, remaining well hydrated while experiencing heat strain is essential, as fluids perform a thermoregulatory role through maintaining sweating rates and skin blood flow responses; in turn reducing the amount of heat stored in the body (Hunt, 2011; Sawka, Montain, & Latzka, 2001).

As ambient temperatures and humidity rise it becomes more difficult for a worker's thermoregulatory responses (i.e. vasodilation and sweating) to maintain a typical CBT (between 36-38°C), potentially resulting in fatigue and hyperthermia (Brake & Bates, 2002; Kondo et al., 2009; Nielsen, 1994; Raymann & Van Someren, 2007; Vogt, 1998). Increased humidity impedes sweat evaporation due to the concentration of water vapour in the air. Once the air becomes completely saturated with vapour (100% humidity) evaporation will cease. In addition, protective personal equipment (PPE) can also preclude sweating and subsequent heat dissipation (Hardcastle, Kenny, Stapleton, & Allen, 2009). Protective helmets and cumbersome, or water impermeable, garments may prevent adequate air circulation resulting in reduced sweat evaporation. As a result, the ACGIH (2011) recommends that appropriate adjustments be made to the TLV for heat stress based on a clothing correction (e.g. a correction of +3°C be made to the WBGT if a worker is wearing a double-layer of woven material).

The risk of heat strain exists for any worker wearing protective clothing and performing physical labour while immersed in environments with high temperatures and humidity (Donoghue, 2004; Donoghue & Bates, 2000; Hardcastle, Kenny, Stapleton, & Allen, 2009). The likelihood of experiencing heat strain is even greater for older individuals or those with an elevated body mass index (BMI) (Dehghan et al., 2013; Donoghue & Bates, 2000; Leveritt, 1998). Poor overall health, physical fitness, and hydration status may also contribute to heat intolerance, resulting in more severe reactions to heat strain (Brake & Bates, 2003; Hunt, 2011; Leveritt, 1998). Conversely, preventative measures such as maintaining hydration, self-adjustment of work rate (self-pacing), and acclimatization can be utilized by workers to negate the experience and side effects of heat strain (Brake & Bates, 2001; Leveritt, 1998; Miller, Bates, Schneider, & Thomsen, 2011; Radakovic et al., 2007; Varley, 2004).

Night workers exposed to warm, humid environments may experience fatigue for two additional reasons. These workers contend with the heat stress and fatigue generated by elevated temperatures but also the influence of circadian rhythms. Under normal circumstances, CBT is usually at its nadir around 02:00 to 04:00 due to natural circadian effects (Hui et al., 2011; Wright, Hull, & Czeisler, 2002). As heat dissipates from the body via the skin, with subsequent lowering of CBT, skin temperature actually increases. An elevated skin temperature is associated with an increased sleep propensity, leaving individuals feeling sleepy and less vigilant (Raymann, Swaab, & Van Someren, 2005). In addition, when CBT is low, physical energy, mood, vigilance, concentration, and work efficiency are also diminished (Hui et al., 2011). This less-than-peak performance can leave workers making poor decisions, taking risks, and being easily distracted. These cognitive responses to fatigue likely contribute to the increased prevalence of human error-related accidents occurring during night shifts (Harrington, 2001).

Consequently, individuals working consecutive, extended night shifts in hot environments are often fatigued and may be functioning at decreased levels of cognition, however the extent of this problem has yet to be determined (Brake & Bates, 2001; Hancock & Vasmatzidis, 2003).

1.4 Current Study

To this author's knowledge, the effects of sleep deprivation, shift work, and exposure to heat on alertness have never before been studied simultaneously in a sample of hard rock underground miners. Sleep deprivation, altered circadian patterns, and working in environments with high temperatures each result in increased daytime fatigue and decreased attentional capacity (Durmer & Dinges, 2005; Haus & Smolensky, 2006; Westel, 2011). Workers suffering from any combination of these factors may be at an elevated risk for occupation-related injury or illness, especially for those already working in a hazardous workplace. When these factors combine the possibility for an interaction exists, which could result in greater impairment than caused by any single factor (Legault, 2011). This degree of cognitive detriment is possible for underground miners who work extensive periods of time, in hot environments, after not sleeping enough and having worked over previous days. Consequently, a better understanding of the relationships between fatigue and cognition may lead to increased worker safety.

Previous research has explored the relationships between shift work, extended shifts, sleep deprivation, and decreased cognitive function at length (Dinges, 1995; Rosa, 1995; Whitmire et al., 2009); however, workplace fatigue research has been conducted primarily in non-industrial employees such as medical residents (Philibert, 2005), nurses (Ruggiero, 2003), truck drivers (McCartt et al., 2000), and airplane pilots (Neri et al., 2002). This gap in the literature is an important one to address, especially due to the additional impairments in cognition that result from working in a hot environment such as an underground mine. Such information will inform researchers and occupational health and safety experts of the level of executive function miners are experiencing as well as the potential for serious work-related accidents.

This study will also inform stakeholders of the fluctuations in cognition and fatigue that workers experience in a variety of different conditions. Changes in cognition and fatigue can be analyzed over a single shift or over multiple shifts in succession without any major disruption to the participant's daily activities. Comparisons between a participant's levels of fatigue and cognition can be made between the first shift worked and the third or fourth shift worked in a row. Differences in cognition and fatigue can be compared between day and night shifts, as well as differences between days on and days off. Relevant analyses are numerous and will provide insight into how work schedules influence cognitive functioning.

Finally, the information gained from this study can be used to better inform the mining industry in regards to the relationships between fatigue, cognitive function, and the safety of those working in hot environments. It is important for workplace safety that employers understand the environment, both physical and mental, that their employees are working in. In most cases, workers suffering from sleep deprivation, and the resulting daytime fatigue, may not even know the degree of impairment that they are working under.

1.4.1 Study Design and Research Questions

This research will be conducted as an observational field study using a within-subjects design. A combination of subjective and objective measures of sleep behaviour and quality, as well as cognitive data and physiological data will be utilized in order to answer the study's research questions. The current study will seek to answer the following research questions:

1) What are the consequences of sleep deprivation, circadian rhythm disruption, and heat exposure on the cognitive function of underground miners? Are workers more likely to experience potentially dangerous situations due to their decreased attention and cognitive capacity?
2) How does the level of fatigue and cognition experienced by workers fluctuate over the course of a single shift, successive shifts or a series of rotating day and night shifts?
3) Does an interaction exist between sleep deprivation, circadian rhythm disruption, and heat exposure - exacerbating the degree of impairment in the cognitive function of miners?

By studying cognition, sleep deprivation, circadian rhythm disruption, and heat exposure simultaneously in underground, hard rock miners new information may be revealed concerning the interactions between several fatigue-inducing factors. A better understanding of these factors and the extent of fatigue in miners is important to bolster health and safety in mining, and other industrial, environments. Once more information is obtained, the potential for reducing human error-related accidents may also exist. Data obtained from this study will also provide information regarding a population of workers that is often over-looked.

Chapter 2

2 Experimental Methods

2.1 Participants

Twenty (n=20) male underground miners from four different mine sites completed the study. Participants were all between the ages of 34-51 and worked 10.5 hour shifts underground, operating heavy machinery (excluding vehicles with air-conditioned cabs). All participants worked the same 28-day rotation pattern of scheduled work days and days off (day shifts, days off, night shifts, days off); the only differences in work shifts was start and end times which varied slightly between mine sites.

Individuals were asked to disclose any previously diagnosed sleep pathologies (e.g. sleep apnea, insomnia) and if they were taking medications that would alter their sleep (e.g. antidepressants). We also asked volunteers to disclose any heavy alcohol or substance use. This was done to eliminate potential confounds that sleep pathology and/or substance abuse would have on sleep quality and attention metrics (Roehrs & Roth, 2001).

2.2 Instruments and Measures

2.2.1 Actigraphy

Actigraphy was measured using an ActiSleep+^{TM} activity monitor (ActiGraph, Pensacola, Florida). Actiwatches were worn by participants on the wrist of their non-dominant hand. Participants were asked to remove the actiwatches prior to showering or partaking in any activity where their hands would be submerged underwater (bathing, washing dishes, etc.). Sampling rate of the actigraphs was 30 Hz (one sample every 33.3 milliseconds) and data was saved in 30 second epochs. Actigraphy data was downloaded using ActiLife^{TM} software (ActiGraph, Pensacola, Florida), at which time the Cole-Kripke algorithm (Cole et al., 1992) was selected for determining sleep/wake periods. The Cole-Kripke algorithm was developed using an adult sample and has been shown to accurately distinguish sleep from wakefulness (88%-91% accuracy) (Cole et al., 1992; de Souza et al., 2003). In addition, actigraphic estimates of sleep onset, total sleep time, and sleep efficiency provided by the Cole-Kripke algorithm correlate highly with corresponding PSG scores (Cole et al., 1992; de Souza et al., 2003). Actigraphic variables, such as total time spent in bed (TIB), total time spent sleeping (TST), wake time after sleep onset (WASO), and sleep efficiency (SE), were reported.

2.2.2 Sleep Log

Subjective sleep data was collected from participants using an investigator-developed sleep log (Appendix B). Participants were asked to self-report on daily activities including number of caffeinated beverages consumed, wake time, “lights out” time, and any naps. In the event that discrepancies appeared in the actigraphy data subjective reports from the sleep log were examined.

2.2.3 Psychomotor Vigilance Test

For the purposes of this study a brief, 3 minute version of the PVT, the PVT-Brief (PVT-B), was developed based on guidelines described in previous literature (Basner & Dinges, 2011; Basner, Mollicone, & Dinges, 2011; Dinges & Powell, 1985; Thorne et al., 2005). The PVT-B was pre-programmed onto an Archos 43 Internet Tablet™ (Archos Inc., Greenwood Village, Colorado), an Android-based handheld device. The wireless signal emitter, vibration output, and sound output were disabled on the Archos™ tablet. The only accessible features on the tablet were the PVT-B and any additional measures required for the study.

2.2.4 Questionnaires

Demographic data was obtained from all participants using an investigator-developed questionnaire (Appendix C). In addition to demographics, health-related information such as body mass index (BMI; kg/m^2), current use of prescription or over-the-counter medication, and persistent medical conditions was also collected.

Participants completed the Behavior Rating Inventory of Executive Function – Adult version (BRIEF-A) (PAR Inc., Lutz, Florida; Roth, Isquith, & Gioia, 2005), the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) (Appendix D), and the Epworth Sleepiness Scale (ESS) (Johns, 1991) (Appendix E). The ESS and the Karolinska Sleep Scale (KSS) (Åkerstedt & Gillberg, 1990) (Appendix F) were pre-programmed onto the Archos tablet assigned to each participant. The tablet prompted participants to complete the KSS prior to each scheduled PVT-B and the ESS after finishing the final PVT-B of the study day.

In addition, an investigator-developed questionnaire was used to determine the amount of fluid (beverages) consumed by the participant in the preceding five hours (Appendix G). The Archos tablet prompted participants to complete this questionnaire prior to every PVT-B completion.

2.2.5 Core Body Temperature

Ingestible CorTemp™ sensors (HQInc., Palmetto, Florida) were utilized to measure core body temperature. Sensors transmitted data wirelessly to a CorTemp™ data recorder kept on the participant's person. Sensors sampled core body temperature (in degrees Celsius) every 20 seconds. Temperature recordings were downloaded from the CorTemp™ data recorders using CorTracker™ software (HQInc., Palmetto, Florida).

2.2.6 Environmental Air Temperature and Relative Humidity

A Veriteq™ temperature and relative humidity data recorder (Veriteq Instruments Inc., Richmond, British Columbia) was used to log ambient air temperature (in degrees Celsius) and relative humidity in the participant's work surroundings (underground). The data recorder logged a sample every 60 seconds. Data was downloaded using Veriteq Spectrum Software™ (Veriteq Instruments Inc., Richmond, British Columbia).

2.3 Statistical Analyses

Psychomotor vigilance test RTs below 100 ms were considered false starts, a result of participants responding early in anticipation of the stimulus, and excluded from analysis. Reaction times of 3000ms or greater were regarded as errors and omitted from further analysis (Basner & Dinges, 2011; Basner, Mollicone, & Dinges, 2011). To allow for time of day comparison, PVT-B and subjective sleepiness score data (KSS) was separated into four "test time" intervals per shift type (day shift, night shift, and day off). Distinct test time intervals were designated based on shift start and finish times (Table 1). These specific time periods were selected in order to capture a similar range of daily activities regardless of shift (e.g. participants would be commuting to work and beginning their shift during Test Time 1).

Table 1

Designated Time Intervals for Psychomotor Vigilance Test – Brief (PVT-B) and Karolinska Sleepiness Scale (KSS) Data Collection and Analysis

	Test Time 1	Test Time 2	Test Time 3	Test Time 4
Days Off	06:00 – 09:59	10:00 – 13:59	14:00 – 17:59	18:00 +
Day Shifts	06:00 – 09:59	10:00 – 13:59	14:00 – 17:59	18:00 +
Night Shifts	14:00 – 19:59	20:00 – 23:59	00:00 – 03:59	04:00 – 08:00

Descriptive statistics, non-parametric, repeated-measures statistical tests, and Pearson correlations were calculated using IBM SPSS 21. Data points that were greater than three standard deviations away from the mean were considered extreme outliers and eliminated from analyses. An alpha level of 0.05 was set for determining statistical significance.

Cosinor analyses (Minors & Waterhouse, 1988) were calculated with Microsoft Excel 2010. The dependent variable used in the Cosinor analysis was the PVT-B RT. If the RT data was better fitted to a cosine wave than a straight line (indicated by a $p < 0.05$) and the % fit of data points to the cosine rhythm was ≥50%, then acrophase (peak in rhythm), mesor (rhythm-adjusted mean), and amplitude (difference between the peak and mean value of the wave) were determined (Figure 2) (Minors & Waterhouse, 1988; Montagnese et al., 2009).

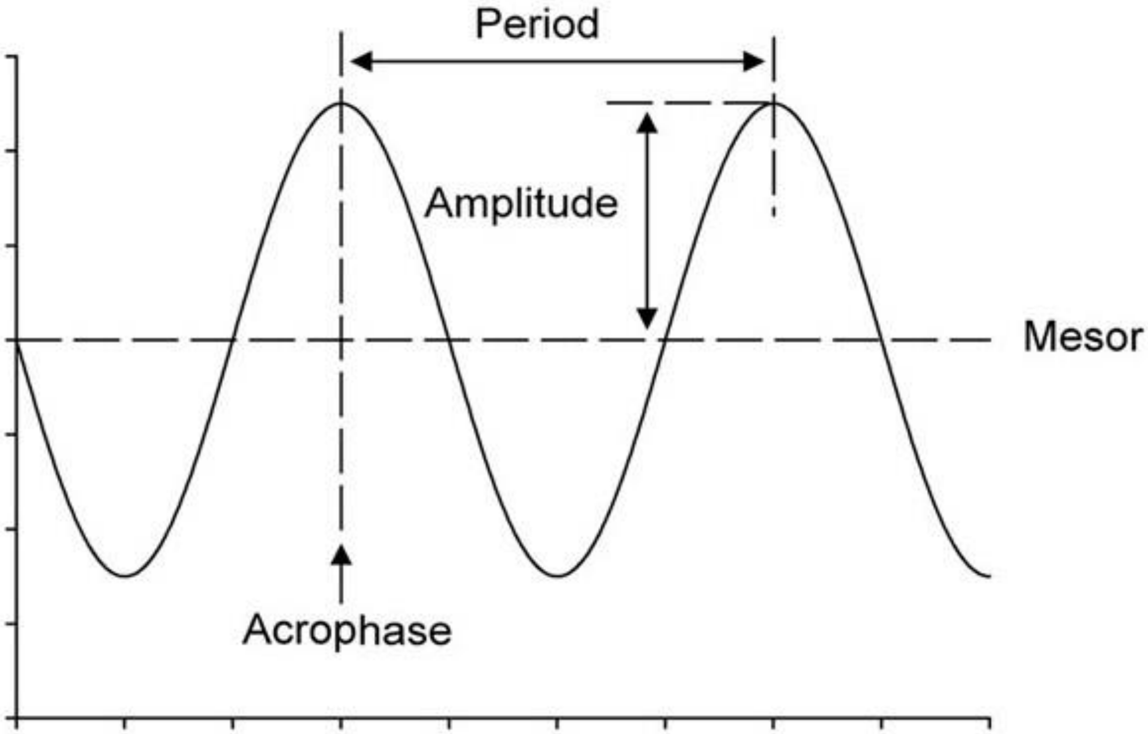


Figure 2. Schematic of an oscillatory wave depicting the outcome variables (amplitude, mesor, and acrophase) of a Cosinor analysis. Reprinted from "The circadian rhythm of body temperature," by R. Refinetti, 2010, *Frontiers in Bioscience, 15,* 564-594. doi: 10.2741/3634.

When applicable, the raw T_{db} and RH data collected using the Veriteq™ data recorder were utilized to find an average T_{db} and RH during the 15 minutes preceding PVT-B completion. In order to determine the T_{wb} for the 15 minutes prior to PVT-B completion, the obtained average T_{db} and RH values were applied in the equation described by Stull (2011) and calculated in Excel 2010. Once T_{wb} values were calculated, an average WBGT for the same time period could be determined using the formula:

$$T_{WBG} = 0.7T_{wb} + 0.3T_{db}$$

While calculating the WBGT, T_{db} was used in the place of T_g following the assumption that the two measures seldom differ in underground mining environments owing to the absence of radiating heat sources (e.g. solar or blast furnaces) (Donoghue, Sinclair, & Bates, 2000; Hardcastle & Butler, 2008). The calculated average WBGT values were used in subsequent non-parametric analyses that have been previously described.

2.4 Study Procedure

Participants were recruited through information sessions conducted during meetings held on days that workers were scheduled to work in the office (once every 28 days). Data was collected from each participant for up to 30 consecutive days – an entire rotating shift schedule. Depending on work location, day shifts started between 05:30 – 07:30 and ended between the hours of 16:00 – 18:00, and night shifts began between 17:30 – 19:30 and concluded between 04:00 – 06:00. During the course of the study participants were not restricted from working overtime, either additional or prolonged shifts. Participants were not subjected to any schedule changes as a result of the research study, except brief, scheduled meetings before selected shifts to exchange equipment.

The first meeting occurred on the first day of testing; at that time participants provided informed consent and were supplied with the required equipment (ActiGraph™ and pre-programmed Archos™ device) and instructed on its use. Participants completed practice sessions on the PVT-B to familiarize themselves with the task. At the same time participants were given a sleep log to fill out daily and a package of questionnaires (demographics, PSQI, ESS, and BRIEF-A) to complete. Subsequent meetings were scheduled to occur at the beginning of two separate day shifts (Day1 and Day 3 of a series of day shifts) and two separate night shifts (Night 1 and Night 3 in a series of night shifts) in order to retrieve and exchange some additional equipment.

Both PVT-B data and actigraphy were collected daily for the duration of the study.

The Archos™ tablet prompted participants to complete the PVT-B and previously described questionnaires at four, predetermined times throughout the day or night, based on the participant’s shift schedule. PVT-B trials were not scheduled during anticipated sleep times (nights during scheduled day shifts, days during scheduled night shifts).When prompted, participants were asked to complete the PVT-B at a time that it would not interfere with their immediate schedule (e.g. operating machinery, driving a vehicle, etc.). PVT-B trials were time-stamped which allowed for time-of-day comparisons.

In addition, participants met with a researcher prior to four predetermined shifts: the first and third day shift of a series of consecutive day shifts (separated by 48 hours) as well as the first and third night shift in a sequence of night shifts. At these times workers were provided with a single CorTemp™ sensor, a CorTemp™ data recorder, and a Veriteq™ temperature and humidity recorder. Participants secured the Veriteq™ data recorders to the piece of machinery they would be working on that day. Placement was such that ambient temperature and humidity was recorded without the influence of the operating equipment. Both data recorders were collected from participants at the end of the shift.

On the final day of the study period a researcher met with the participants to collect the research equipment and the completed sleep log.

Chapter 3

3 Results

3.1 Demographics

Descriptive statistics were calculated for demographic variables (age, BMI, and number of years in current job) as well as the total ESS and the global PSQI scores obtained from participants at the beginning of the study (n = 19). One participant was excluded from statistical analyses due to their highly irregular work schedule. Participants reported a mean age of 41.5 years (SD = 5.1 years) and an average BMI of 28.4 kg/m^2 (SD = 2.7 kg/m^2). Additionally, of the 19 participants in the study seven (36.8%) were smokers. On average, participants spent 11.2 years (SD = 4.6 years) employed in their current job and commuted 27.1 minutes (SD = 15.6 minutes) to work. Participant age was significantly correlated with the number of years worked in their current job [r (19) = .512, p = 0.025] but no other correlations existed between demographic variables (age, BMI, number of years on job) or subjective sleep questionnaire scores (ESS and PSQI).

Based on self-reported BMI of 30 or greater, 16 participants (84.2 % of the sample) were overweight or obese as characterized by the Health Canada (2003) criteria. When compared to Canadian population norms, participants' mean BMI did not differ significantly in either the 20-39 age range (n = 8; Z = 0.98, p > 0.05) or the 40-59 age range (n = 11; Z = 0.20, p > 0.05) (Shields et al., 2010). At the time of recruitment into the study participants' mean ESS score was within the normal range of subjective daytime sleepiness (< 10), despite three participants (15.8% of the sample) reporting an excessive level of daytime sleepiness (≥ 10) (Johns, 1991). Conversely, 11 participants (61.1% of the sample) were determined to be "poor sleepers", with a score of ≥ 5 on the PSQI (Buysse et al., 1989). Results suggested that the number of participants distinguished as “poor sleepers” differed significantly by self-reported BMI category (normal weight vs. overweight/obese). One hundred percent of poor sleepers were determined to be overweight/obese, χ^2 (1, n = 18) = 5.56, p = 0.017.

Z-tests were performed to determine whether participants (n = 19) differed from age-matched normative data on any of the BRIEF-A subscales or indices (Roth, Isquith, & Gioia, 2005). No significant differences were found. Two participants, 10.5% of the sample, revealed clinically elevated scores (T-score of 65+) on the Global Executive Composite (GEC), the scale reflecting diminished overall executive function.

3.2 Actigraphy

Due to an equipment malfunction, actigraphy data was not obtained for one participant leaving an effective sample size of 18. Overall, participants’ mean SE was 84.6% (SD = 4.0%). When compared to age-matched normative data participants exhibited significantly diminished SE [30-39 year olds (n = 8): Z = -14.62, p < 0.001; 40-49 year olds (n = 9): Z = -4.44, p < 0.001]. In addition, participants’ achieved an average TST of 362.2 minutes (SD = 50.1 minutes), approximately six hours of sleep. This sleep duration is significantly less TST than reported by age-matched norms [30-39 year olds (n = 8): Z = -7.64, p < 0.001; 40-49 year olds (n = 9): Z = -3.19, p < 0.001] (Williams, Karacan, & Hursch, 1974). Furthermore, during their sleep periods participants averaged 428.2 minutes (SD = 54.1 minutes) of time in bed, however 64.5 minutes (SD = 17.5 minutes) of that time was spent awake following initial sleep onset.

A Friedman test was utilized to determine whether shift type (days off, day shifts, and night shifts) influenced the participants’ sleep efficiency, time spent in bed, wake after sleep onset, or total sleep time obtained during the major sleep period prior to beginning a shift (or a day off). Participants' major sleep periods occurred during the night while on days off or day shifts. Conversely, the major sleep period took place during the daytime while participants worked scheduled night shifts. Post-hoc analyses, using Wilcoxon signed-rank tests, revealed that no significant differences in SE existed between days-off (M = 84.5%, SD = 4.1%), day-shifts (M = 85.8%, SD = 5.0%), and night-shifts (M = 83.5%, SD = 4.5%) [χ^2 (2, n = 18) = 3.44, p = 0.179]. However, significant differences were observed between shift types in TIB [χ^2 (2, n = 18) = 19.44, $p < 0.001$], WASO [χ^2 (2, n = 18) = 14.78, p = 0.001], and TST [χ^2 (2, n = 18) = 13.44, p = 0.001].

Participants spent significantly less TIB, expressed in minutes (mins), prior to day shifts (M = 389.5, SD = 53.5) compared to day offs (M = 450.5, SD = 65.6) [Z (18) = -3.68, $p < 0.001$], and night shifts (M = 429.2, SD = 58.7) [Z (18) = -3.11, p = 0.002] (Figure 3a). Workers also experienced less WASO (mins) before day shifts (M = 53.8, SD = 18.6) versus day offs (M = 68.8, SD = 19.8) [Z (18) = -2.98, p = 0.003], and night shifts (M = 67.7, SD = 18.7) [Z (18) = -3.20, p = 0.001] (Figure 3b). Following a similar trend, the TST (mins) participants obtained during the sleep period prior to day shifts (M = 334.7, SD = 53.2) was significantly shorter than before days off (M = 380.2, SD = 58.3) [Z (18) = -3.42, p = 0.001], and night shifts (M = 359.4, SD = 57.5) [Z (18) = -2.03, p = 0.043] (Figure 3c).

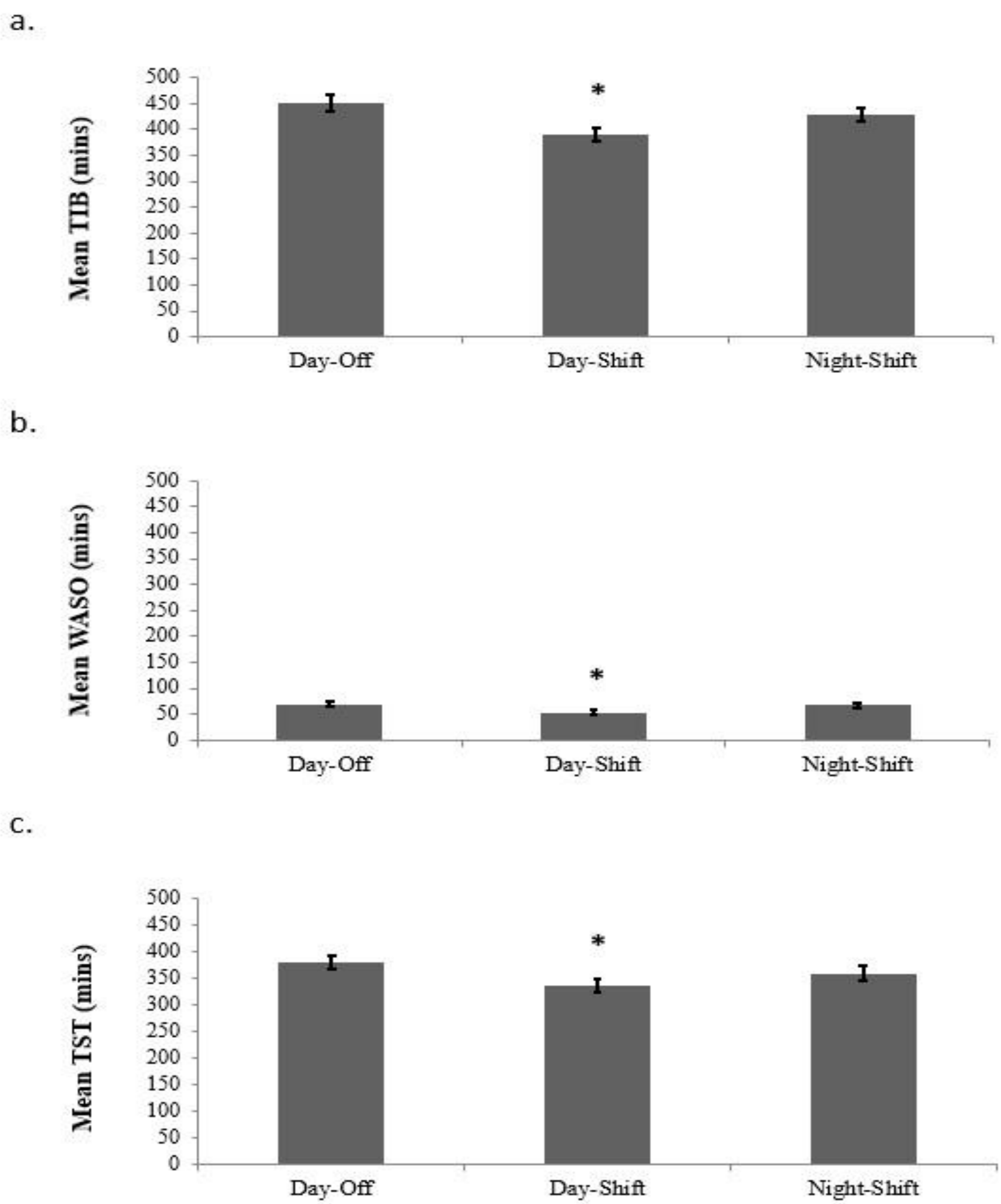


Figure 3. Mean Time in Bed (TIB) (a), mean Wake After Sleep Onset (WASO) (b), and mean Total Sleep Time (TST) (c) observed during participants' sleep periods prior to days off, day shifts, and night shift. Error bars represent standard error of the mean. Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

Actigraphic variables were analyzed, using Friedman tests, across consecutive shifts of the same shift type (days off, day shifts, or night-shifts). This was done to establish whether participants' sleep quality and quantity varied after working several of the same shifts or when transitioning into a new shift type. No differences existed between consecutive shifts of the same shift type in SE [days off: χ^2 (4, n = 15) = 7.20, p = 0.126; day shifts: χ^2 (4, n = 11) = 3.86, p = 0.426; night shifts: χ^2 (4, n = 9) = 2.04, p = 0.728]. Similarly, no differences between consecutive shifts of the same shift type were found when TIB was compared [days off: χ^2 (4, n = 15) = 8.91, p = 0.063; day shifts: χ^2 (4, n = 11) = 2.18, p = 0.702; night shifts: χ^2 (4, n = 9) = 4.44, p = 0.349]. In addition, no differences were found for WASO when consecutive shifts of the same type were analyzed [days off: χ^2 (4, n = 15) = 8.76, p = 0.067; day shifts: χ^2 (4, n = 11) = 1.96, p = 0.742; night shifts: χ^2 (4, n = 9) = 2.39, p = 0.664]. Finally, no significant differences existed between consecutive shifts of the same shift type for TST [days off: χ^2 (4, n = 15) = 8.37, p = 0.079; day shifts: χ^2 (4, n = 11) = 2.04, p = 0.729; night shifts: χ^2 (4, n = 9) = 5.88, p = 0.209].

3.3 Psychomotor Vigilance Test

Psychomotor vigilance test compliance ranged widely between participants (n = 19), from 15% to 91%; with an average PVT-B completion of 50% throughout the study duration (approximately 56 PVT-Bs). Reaction time, expressed in milliseconds (ms), and number of attentional lapses observed during PVT-B trials were used to determine how participants' alertness fluctuated over the course of a typical shift or multiple consecutive shifts. Differences in RT and number of lapses were also compared between different shift types (e.g. day shift versus night shift). To perform these comparisons PVT-B trials were separated into four categories corresponding to the time of day the PVT-Bs were completed. These intervals were: Test Time 1, Test Time 2, Test Time 3, and Test Time 4 (See Table 1).

Using Friedman tests the RTs of participants were compared over the course of a typical shift for each shift type (days off, day shifts, and night shifts). Post-hocs were performed using Wilcoxon tests. No differences in RT occurred over the course of days off [χ^2 (3, n = 12) = 2.50, p = 0.475] or day shifts [χ^2 (3, n = 14) = 1.92, p = 0.589] but differences were observed during night shifts, χ^2 (3, n = 13) = 9.28, p = 0.026. Participants achieved significantly faster RTs during the second test time (M = 287.67, SD = 31.45) of night shifts compared to the first (M = 311.33, SD = 36.82) [Z (13) = -2.27, p = 0.023] and fourth test times (M = 356.45, SD = 69.08) [Z (13) = -2.90, p = 0.004], but not the third test time (M = 312.69, SD = 55.08) [Z (13) = - 1.29, p = 0.196] (Figure 3). A significant difference in RT was also observed between the first and fourth test time of the night shift [Z (13) = -2.27, p = 0.023] (Figure 4). The Friedman test was calculated with the number of lapses participants experienced as the dependent variable. Unlike the analyses for RT, no significant differences were observed for lapses across the course of days off [χ^2 (3, n = 11) = 4.86, p = 0.183], day shifts [χ^2 (3, n = 14) = 0.58, p = 0.901], or night shifts [χ^2 (3, n = 13) = 7.06, p = 0.070]. However, differences in lapses did approach statistical significance during night shifts – similar to the trend observed in RT.

Changes in RTs and lapses occurred across consecutive shifts of the same shift type (days off, day shifts, and night shifts) were evaluated using Friedman tests. Mean RTs and lapses were calculated by averaging the data from all four test intervals (Test Time 1 through Test Time 4) obtained during a shift, and were then compared with up to five consecutive shifts of the same shift type (days off, day shifts, and night shifts). No differences in RTs or lapses were observed over consecutive days off [χ^2 (4, n = 12) = 8.53, p = 0.074, χ^2 (4, n = 12) = 8.65, p = 0.070], consecutive day shifts [χ^2 (4, n = 11) = 1.82, p = 0.769; χ^2 (4, n = 10) = 3.48, p = 0.482], or consecutive night shifts [χ^2 (4, n = 9) = 1.24, p = 0.871; χ^2 (4, n = 9) = 2.18, p = 0.703].

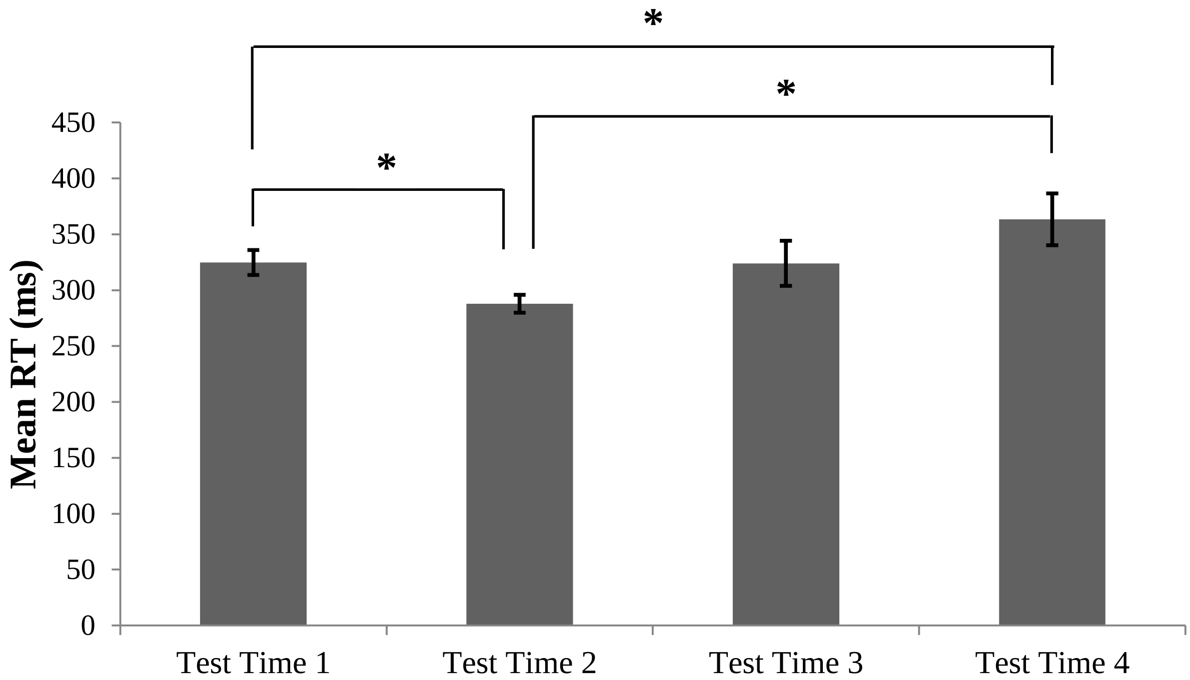


Figure 4. Participants' mean reaction time (RT) achieved on the Psychomotor Vigilance Test – Brief (PVT-B) at four test intervals during scheduled *night shifts* at work. Error bars represent standard error of the mean. Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

Post-hoc analyses were conducted to distinguish whether the shift type being worked (day off, day shift, or night shift) influenced participants' RT. Reaction times obtained during each pre-determined Test Time (1 through 4) were compared between these shift types. Results suggested that shift type did not affect RT during Test Time 1 [χ^2 (2, n = 14) = 1.86, p = 0.395], Test Time 3 [χ^2 (2, n = 14) = 1.00, p = 0.607], or Test Time 4 [χ^2 (2, n = 14) = 5.57, p = 0.062]; though significant differences were observed at Test Time 2, χ^2 (2, n = 12) = 6.50, p = 0.039. Participants displayed a faster RT during Test Time 2 while on night shifts (late evening; M = 290.81, SD = 31.05) compared to days off (early afternoon; M = 313.28, SD = 29.42) [Z (12) = -2.28, p = 0.023], however day shifts (early afternoon; M = 320.60, SD = 41.87) did not differ from days off or night shifts (Figure 5). Shift type did not appear to influence participants' lapses regardless of test time [Test Time 1: χ^2 (2, n = 14) = 2.73, p = 0.256; Test Time 2: χ^2 (2, n = 12) = 2.48, p = 0.290; Test Time 3: χ^2 (2, n = 14) = 0.98, p = 0.612; Test Time 4: χ^2 (2, n = 13) = 0.67, p = 0.717].

3.3.1 Extended Wake Time

Non-parametric tests revealed that significant differences existed in the durations of time participants spent awake before completing PVT-Bs at Test Time 1 [χ^2 (2, n = 13) = 16.62, p < 0.001], Test Time 2 [χ^2 (2, n = 10) = 18.20, p < 0.001], Test Time 3[χ^2 (2, n = 12) = 19.50, p < 0.001], and Test Time 4 [χ^2 (2, n = 11) = 10.36, p = 0.006]. Prior to completing the first PVT-B of the subjective wake interval (Test Time 1), participants spent significantly more time awake (mins) while on night shifts (M = 296, SD = 122) compared to while on days off (M = 138, SD = 84) [Z (13) = -2.62, p = 0.009], and day shifts (M = 136, SD = 63) [Z (13) = -3.18, p = 0.001](Figure 6a). The duration of time participants spent awake prior to Test Time 1 did not differ significantly between days off and day shifts (Z (13) = -1.75, p = 0.861).

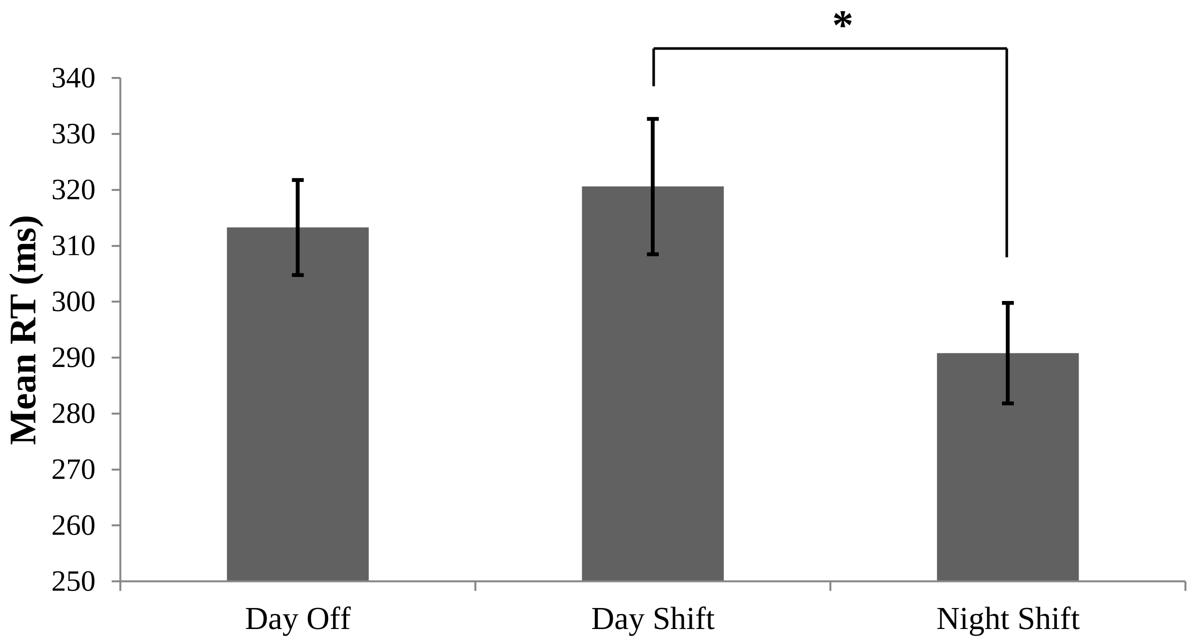


Figure 5. Participants' mean reaction time (RT) achieved on the Psychomotor Vigilance Test – Brief (PVT-B) during *Test Time 2* of days off, day shifts, and night shifts. Error bars represent standard error of the mean Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

Leading up to Test Time 2, the second subjective wake interval, participants' duration of wakefulness was significantly different between all three shifts types. Participants spent the greatest length of time awake prior to Test Time 2 while on night shifts (M = 705, SD = 172) in comparison to days off (M = 235, SD = 133) [*Z* (10) = -2.80, *p* = 0.005], as well as day shifts (M = 380, SD = 51) [*Z* (10) = -2.80, *p* = 0.005] (Figure 6b). In addition, while on day shifts participants were awake significantly longer prior to Test Time 2 than on days off [*Z* (10) = -2.50, *p* = 0.013].

A similar trend to the results observed for Test Time 2 was noted for Test Time 3; significant differences were found between all three shift types. Similarly, while participants were on night shifts they spent significantly more time awake leading up to the third PVT-B of the study day (M = 844, SD = 69) compared to their days off (M = 522, SD = 100) [*Z* (12) = -3.06, *p* = 0.002] and day shifts (M = 665, SD = 81) [*Z* (12) = -3.06, *p* = 0.002] (Figure 6c). The difference in time spent awake between days off and day shifts was also significant [*Z* (12) = -2.59, *p* = 0.010].

For the final PVT-B trial of the wake time, significant differences were observed for the duration of wakefulness (time spent awake) preceding Test Time 4 between days off (M = 781, SD = 85) and day shifts (M = 919, SD = 73) [*Z* (11) = -2.40, *p* = 0.016], as well as night shifts (M = 1008, SD = 109) [*Z* (11) = -2.93, *p* = 0.003] (Figure 6d). During days off participants spent the least amount of time awake prior to PVT-B trial completion. The difference in time spent awake prior to Test Time 4 on day shifts compared to night shifts approached statistical significance (*Z* (11) = -1.87, *p* = 0.062).

Pearson correlations were calculated to determine whether participant's PVT-B performance, measured by RT and number of lapses, directly correlated with the duration of time spent awake prior to PVT-B testing (wake time) or inversely correlated with the SE or TST of the sleep period prior to PVT-B completion. Separate analyses were conducted for each individual for each shift type (day off, day shift, and night shift). The number of participants who displayed significant correlations ($p < 0.05$) between PVT-B performance and wake time, SE, or TST are listed in Table 2. Non-significant chi-square tests suggested that the number of participants whose PVT-B performance correlated with wake time, SE, and TST was no greater than the frequency expected due to chance alone, regardless of shift.

3.3.2 Circadian Disruption

Participants' RTs were analyzed using a Cosinor analysis to determine whether their alertness fluctuated corresponding with a 24-hour circadian rhythm characterized by a cosine wave (n =19). The mesor, amplitude, and acrophase (Figure 2) of RTs were only calculated if a participant's RTs, grouped by shift type, reliably fit the cosine wave. The "fit" of the data was considered reliable if the fluctuations in RT data were better predicted by the shape of a cosine wave versus a straight line, indicated by a p-value < 0.05 in the cosine analysis, and if 50% or more of the RT data points matched the cosine wave.

Seven participants (36.8 %) displayed significant 24 hour (circadian) periodicity in their RTs during one shift type. One worker exhibited the significant cosine pattern during days off, two while on day shifts, and four of which occurred while on night shifts. No single participant demonstrated circadian-patterned variations of alertness in more than one shift type. The mesor, amplitude, and acrophase of each individual's cosine-fitted RTs are displayed in Table 3.

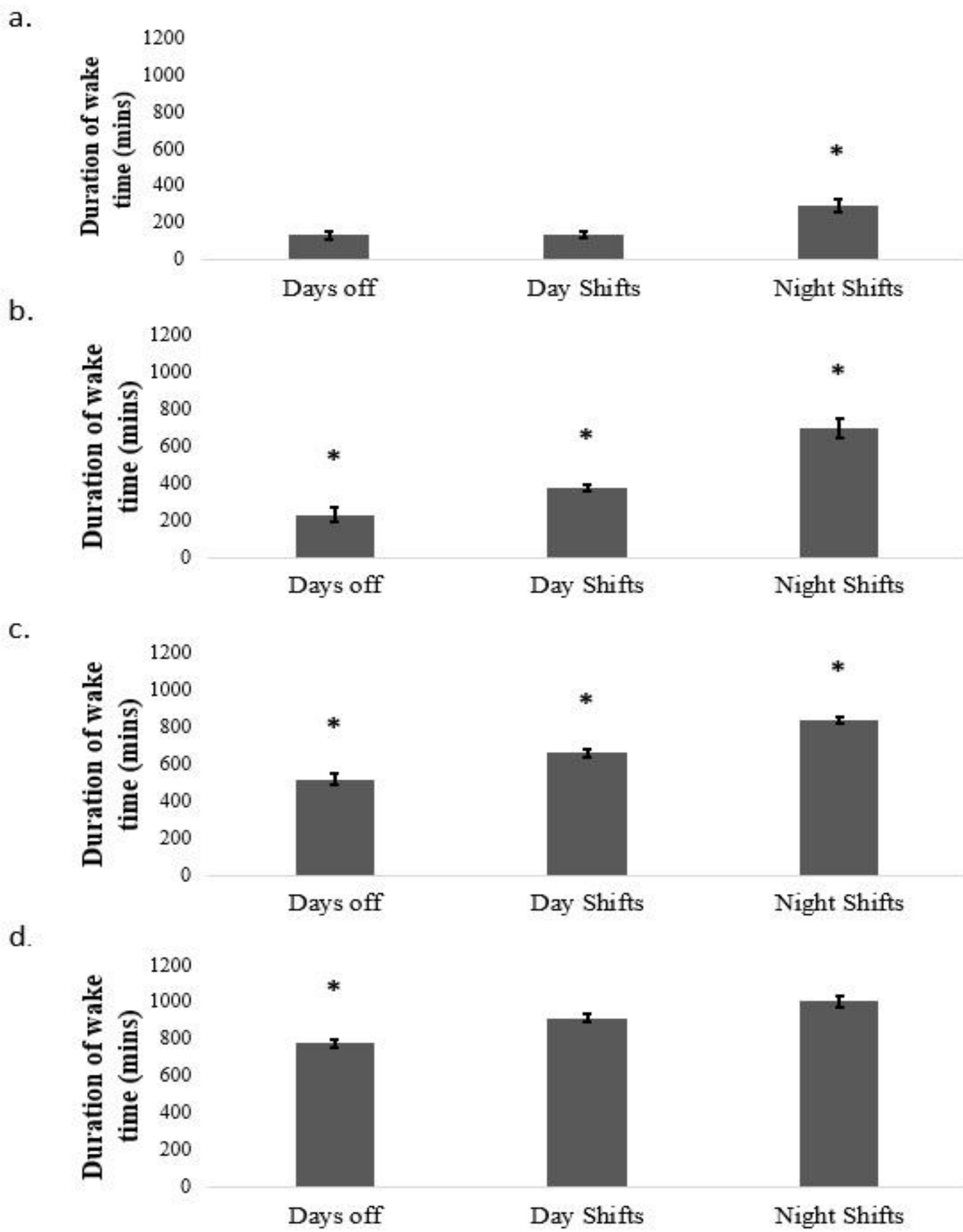


Figure 6. Mean duration of wakefulness (mins) prior to Test Time 1 (a), Test Time 2 (b), Test Time 3 (c), and Test Time 4 (d). Error bars represent standard error of the mean. Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

Table 2

Frequency of Participants whose Psychomotor Vigilance Test – Brief (PVT-B) Performance Correlated with SE or TST of the Preceding Sleep Period or Wake Time Prior to the PVT-B (by Shift Type)

	Reaction Time (ms)			**Number of Lapses**		
Shift Type *(n)*	**1/SE (%)**	**1/TST (%)**	**Wake time (%)**	**1/SE (%)**	**1/TST (%)**	**Wake time (%)**
Days Off *(16)*	-	-	3 (18.8)	-	1 (6.3)	1 (6.3)
Day Shifts *(18)*	-	1 (5.6)	1 (5.6)	-	-	4 (22.2)
Night Shifts *(18)*	2 (11.1)	2 (11.1)	1 (5.6)	2 (11.1)	4 (22.2)	-

Table 3

Mesor, Amplitude, and Acrophase of Participants' Psychomotor Vigilance Test – Brief (PVT-B) Reaction Times Demonstrating a 24-hour Periodicity (by Shift Type)

Shift Type *(n)*	**Mesor (ms)**	**Amplitude (ms)**	**Acrophase (time)**
Day Off* *(1)*	328.21	46.91	02:33
Day Shift *(2)*	281.90	28.02	06:46
	347.49	84.21	21:08
Night Shift *(4)*	333.68	39.80	08:17
	276.75	111.31	14:16
	373.78	62.64	14:36
	302.82	97.98	16:16

Note. A single participant demonstrated a significant 24-hour periodicity in performance on a day off (*) following a series of day shifts.

3.4 Subjective Sleepiness

Friedman tests determined if Karolinska Sleepiness Scale (KSS) scores that were collected concurrent with PVT-B trials during four daily test times, varied across the course of a single shift or between different shift types (n = 16). Results suggest that participants had significant variations in their subjective sleepiness (KSS scores) over the course of a typical day off [χ^2 (3, n = 10) = 10.92, p = 0.012], day shift [χ^2 (3, n = 10) = 9.69, p = 0.021], and night shift [χ^2 (3, n = 10) = 23.88, p < 0.001].

Post-hoc analyses revealed that during their days off, participants reported significantly greater subjective sleepiness during Test Time 4 (M = 5.11) in comparison to Test Time 2 (M = 3.50) [Z (10) = -2.70, p = 0.007], and Test Time 3 (M = 3.48) [Z (10) = -2.60, p = 0.009]. Self-reported sleepiness during Test Time 4 was not significantly higher when compared to Test Time 1 (M = 3.84), although significance was approached [Z (10) = -1.89, p = 0.059] (Figure 7a). A similar result was observed during day shifts, when participants' KSS scores were significantly elevated during the fourth daily test time (M = 5.29) when compared to the second test time (M = 3.82) [Z (10) = -2.70, p = 0.007], and the third test time (M = 3.96) [Z (10) = -2.56, p = 0.011], but not the first test time (M = 4.55) [Z (10) = -1.54, p = 0.123] (Figure 7b).

In the course of a night shift, participants indicated feeling significantly more sleepy during Test Time 4 (M = 6.13) versus Test Time 1 (M = 3.51) [Z (10) = -2.81, p = 0.005], Test Time 2 (M = 3.33) [Z (10) = -2.80, p = 0.005], and Test Time 3 (M = 4.42) [Z (6) = -2.20, p = 0.028] (Figure 7c). In addition, workers had greater KSS scores during Test Time 3 compared to Test Time 1 [Z (10) = -2.50, p = 0.013] and Test Time 2 [Z (10) = -2.70, p = 0.007]. Test Time 1 and Test Time 2 did not differ significantly [Z (10) = -0.51, p = 0.610].

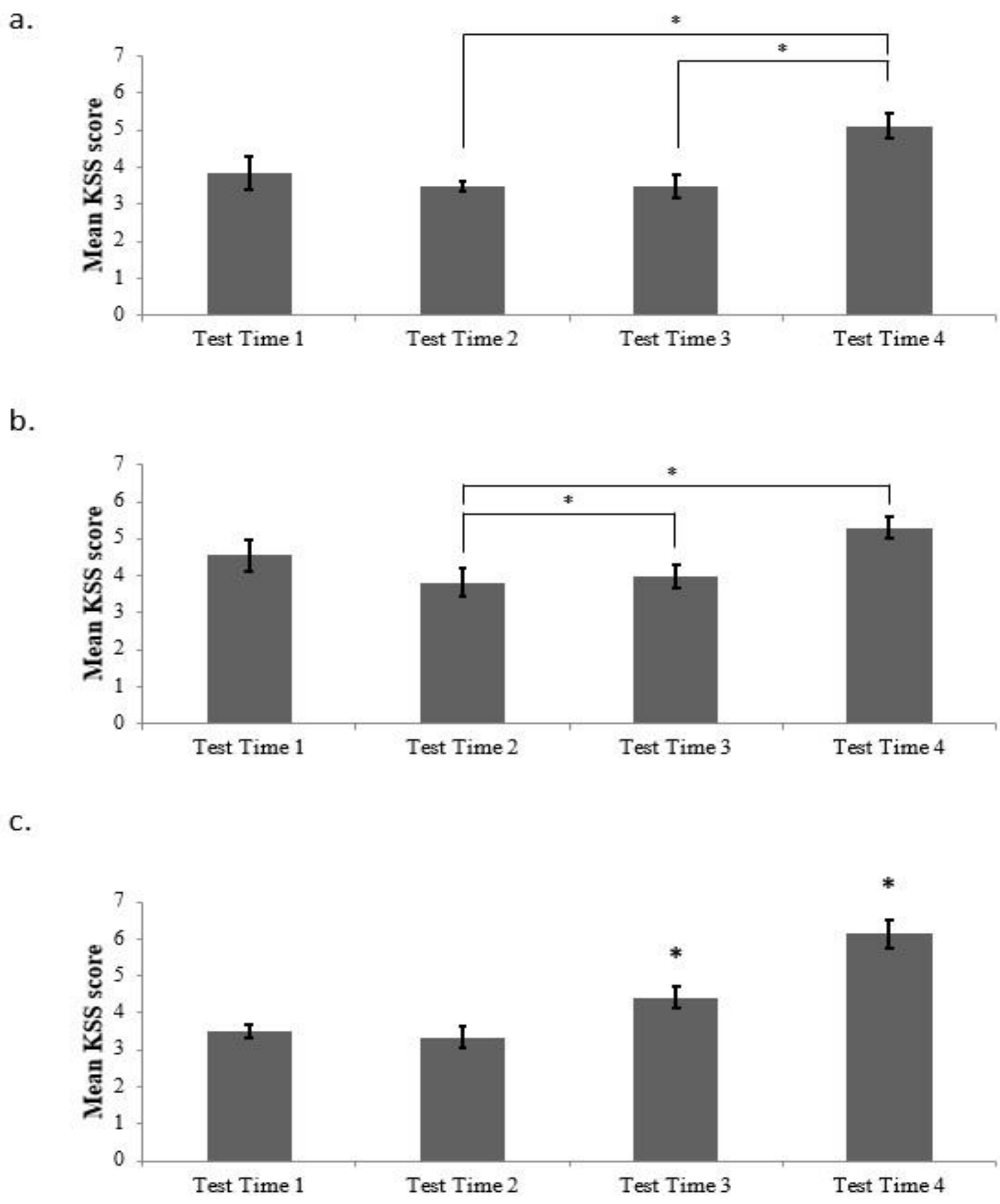


Figure 7. Participants' mean Karolinska Sleepiness Scale (KSS) scores at four test times during days off (a), day shifts (b), and night shifts (c). Error bars represent standard error of the mean. Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

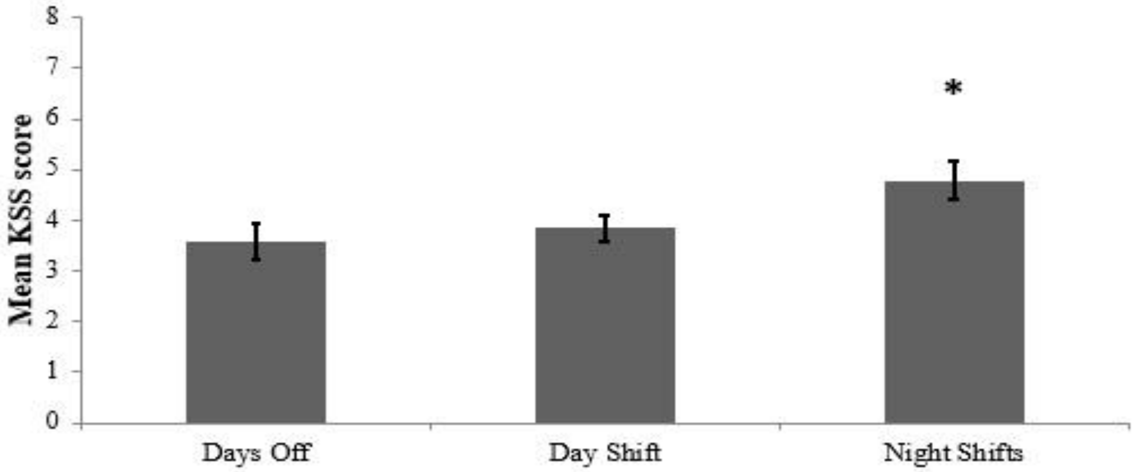
When compared between shift types, workers reported differences in subjective sleepiness at Test Time 3 [χ^2 (2, *n* = 12) = 13.15, *p* = 0.001] and Test Time 4 [χ^2 (2, *n* = 11) = 10.89, *p* = 0.004]. During the third daily test time (Test Time 3) participants experienced significantly more sleepiness on night shifts (M = 4.78) compared to days off (M = 3.59) [*Z* (12) = -2.43, *p* = 0.015] and day shifts (M = 3.84) [*Z* (12) = -2.90, *p* = 0.004] (Figure 8a). Similar results were observed during Test Time 4, participants reported greater KSS scores during night shifts (M = 6.35) versus days off (M = 5.03) [*Z* (11) = -2.80, *p* = 0.005] and day shifts (M = 5.19) [*Z* (11) = -2.44, *p* = 0.015] (Figure 8b).

3.5 Core Body and Environmental Temperature Data

Both environmental data (air temperature and relative humidity) and core body temperature data were obtained from participants during two regularly scheduled day shifts, referred to as Day 1 and Day 2, and two regularly scheduled night shifts, designated as Night 1 and Night 2. Observed environmental temperatures during PVT-B completion ranged from 19.4°C to 33.9°C (M = 26.3°C, SD = 2.9°C) and relative humidity varied from 18.7% to 85.7% (M = 50.6%, SD = 16.0%). The calculated WBGT fell within the range of 15.6°C to 27.3°C (M = 21.3°C, SD = 2.6°C).

The obtained data was analyzed using non-parametric tests to determine whether environmental heat stress or participants' CBT influenced performance on the PVT-B, measured by RT and number of lapses. During these data collection periods, participants' RTs did not differ significantly ($t_{(106)}$ = -0.21, *p* = 0.833) from the average values exhibited throughout the study duration. Furthermore, participants' average RTs did not differ between data collection days (Day 1, Day 2, Night 1 and Night 2) [χ^2 (3, *n* = 9) = 0.87, *p* = 0.833]. Comparisons between the four successive, daily PVT-B test times (Test Time 1 through 4) could not be made.

a.



b.

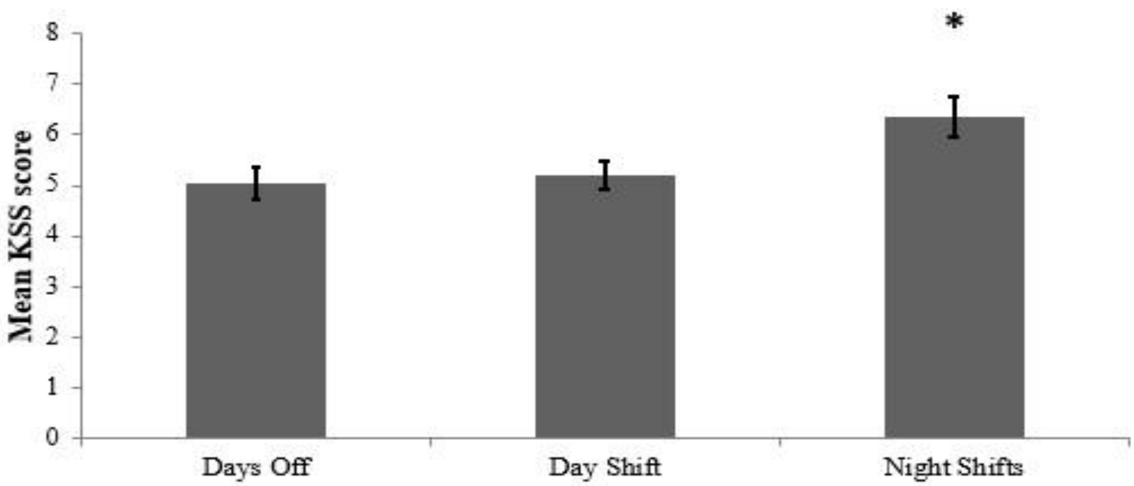


Figure 8. Participants' mean Karolinska Sleepiness Scale (KSS) scores reported during Test Time 3 (a) and Test Time 4 (b) of days off, day shifts, and night shifts. Error bars represent standard error of the mean. Asterisks (*) indicates a significant difference at the $p < 0.05$ level.

The degree of environmental heat stress experienced by participants, reflected by the WBGT, remained consistent between the four data collection periods [χ^2 (3, *n* = 9) = 0.33, *p* = 0.954]. In addition, participants' average CBT did not differ significantly between any of the temperature data collection periods [χ^2 (3, *n* = 5) = 4.40, *p* = 0.218]. Consequently, results from Day 1 and Day 2 were averaged and the same was done for the data collected during Night 1 and Night 2.

Pearson correlations were calculated for participants' day shift and night shift data, comparing their RT, CBT and exposure to heat stress (WBGT) at the time of PVT-B completion; TST and SE obtained during their most recent sleep period; and also, the time they spent awake leading up to completing the PVT-B. Results suggested that during day shifts, regardless of the time of day (Test Time 1, 2, or 3, no data was collected during Test Time 4), participants with a warmer CBT obtained faster RTs [Test Time 1: *r* (9) = -.794, *p* = 0.011; Test Time 2: *r* (12) = -.604, *p* = 0.037; Test Time 3: *r* (9) = -.857, *p* = 0.003; Test Time 4 – no data]. No other correlations were observed during the day shifts in which temperature data was collected. However, during night shifts participants' RT was positively correlated with the TST obtained during the previous sleep period at the beginning of the shift and towards the end of the shift [Test Time 1: *r* (8) = .782, *p* = 0.022; Test Time 3: *r* (13) = .579, *p* = 0.038] but not during mid-shift [Test Time 2: *r* (9) = 0.016, *p* = 0.968]. Participants who slept longer appeared to demonstrate slower RTs. No correlations between RT and CBT or WBGT were observed during night shifts.

Chapter 4

4 Discussion

Fatigue resulting from sleep deprivation, altered circadian patterns, and working in environments with high temperatures can result in greater performance variability and decreased alertness (Durmer & Dinges, 2005; Haus & Smolensky, 2006; Westel, 2011). Consequently, workers suffering from any combination of these fatigue-inducing factors are at an elevated risk for workplace accidents. Although participants' reports of subjective sleepiness and alertness, quantifiable indicators of fatigue, remained stable across the course of multiple consecutive shifts; this samples' levels of sleepiness fluctuated conspicuously during individual days off and work shifts (day and night). In addition, workers' levels of alertness (measured by RT) remained consistent throughout days off and day shifts but decreased significantly during night shifts. This decline in cognitive function may be attributable to participants' chronic sleep deprivation or, potentially, a disruption to participants' circadian rhythms arising from their rotating shift schedules. Though this investigation did not reveal an interaction between the negative effects of sleep deprivation, circadian rhythm disruption, and heat exposure, the possible existence of a deleterious synergy has not been ruled out. Further exploration with more reliable measures of circadian disruption and physiological heat strain can potentially elucidate whether an interaction between these factors exists as well as the extent of its possible influence on the alertness of workers.

Throughout the study period the sleep experienced by this sample of male underground miners was of poor quality and shortened duration. At the time of recruitment participants reported a mean global score of 6.3 (SD = 2.9) on the PSQI; where a score ≥ 5 is indicative of chronic, poor sleep quality (Buysse et al., 1989). Common sleep disturbances noted by participants on the PSQI included difficulty falling asleep, waking up in the middle of the night or early morning, and also coughing or snoring loudly; typical complaints of individuals who follow shift work schedules (Flo et al., 2013). This subjective report of reduced sleep quality was corroborated by the low SE (mean ≤ 85%), measured using actigraphy, experienced by participants during their sleep periods. A low SE denotes that an ample proportion of participants' time in bed was spent being restless or awake.

Moreover, no significant differences in participants' SE were observed between days off, day shifts, or night shifts. This outcome reveals that participants' day-time sleep was of the same quality as their habitual night time sleep. Consequently, these workers experience disrupted sleep even while on days off, a time when sleep-restricted individuals will try to "recover" lost sleep or reset their sleep-wake cycle. Alternatively this result could suggest an adaptive trait, wherein participants' achieve the same quality of sleep despite the incongruent sleep time. Further, SE remained low over consecutive work days, as well as days off, showing no significant signs of improvement, or decline, as work schedules continued.

Although SE naturally degrades with age and health status, participants' SE was significantly reduced below population norms throughout the study duration (Ohayon et al., 2004; Walsleben et al., 2004; William, Karacan, & Hursch, 1974). Moreover, the level of SE that participants maintained during the study was at or below the common cut-off (85%) utilized by clinicians to determine pathologically poor sleep quality (Edinger et al., 2004; Lichstein et al., 2003). The chronically poor SE observed in this sample may be a consequence of participants' overall health. The average BMI (M = 28.4 kg/m^2, SE = 2.7 kg/m^2) of the study's participants was elevated, but average, based on age-matched normative data (Shields et al., 2010); however, being overweight or obese is a common risk factor for developing a sleep disorder such as insomnia or sleep-disordered breathing (SDB) (Hargens et al., 2013). Furthermore, though BMI and subjective sleep quality (measured by the PSQI) were not correlated in this sample, a finding also observed in larger studies, individuals with an elevated BMI commonly experience chronic, poor SE as well as shortened sleep durations (Hargens et al., 2013; Moraes et al., 2013; Redline et al., 2004).

Further analysis of the sleep periods occurring prior to day shifts, night shifts, and days off indicated that participants spent the least TIB, approximately 6.5 hrs, and the shortest TST, roughly 5.5 hours, before working their day shifts. This tendency is likely a result of the early wake times associated with morning shift start times (between 05:30 and 07:30) and the inability of participants to modify their bedtimes to an earlier hour in the evenings. Earlier bedtimes can be unrealistic for these individuals due to social and familial commitments as well as the physiological (circadian) influence which drives individuals to be awake during the evening hours. In addition, though average TST was truncated (5 hrs, 34 mins) prior to day shifts participants also experienced the shortest amount of WASO (53 mins) during these sleep periods, resulting in a degree of SE consistent with that obtained prior to night shifts or while on days off.

Although participants' slept an average of 45 mins longer (6 hrs, 20 mins) on their days off, their TST remained significantly lower than age-matched norms (Ohayon et al., 2004; Walsleben et al., 2004; William, Karacan, & Hursch, 1974). These truncated sleep durations are likely detrimental as many studies suggest that 7-9 hours of sleep per night is required for optimal daily performance (Van Dongen et al., 2003). Similar to the trend observed in SE, participants' TIB, TST, and WASO did not fluctuate significantly across consecutive shifts of the same shift type. These outcomes indicate that participants' are likely not achieving restorative sleep regardless of shift, or while on days off, and are continuing to accumulate sleep debt. Problems with daytime sleepiness and fatigue can arise when sleep quality is insufficient, especially when combined with truncated sleep durations.

This sample of individuals reports experiencing a “normal” degree of daytime sleepiness based on their average ESS score of 6.4 (SD = 3.7) (Johns, 1991). Apparently these individuals did not perceive themselves as suffering from excessive daytime somnolence despite their consistently deficient sleep. Also, the absence of a correlation between subjective sleep quality (reported on the PSQI) and daytime sleepiness (reported on the ESS) is not novel and has been demonstrated in previous studies with larger samples (Buysse et al., 2008). Furthermore, chronic or extended durations of sleep deprivation can have a dampening effect on perceived sleepiness, masking its true extent. Hence why subjective measures are not typically an accurate indication of a worker’s fatigue (Hossain et al., 2003).

Participants’ responses on the KSS, reported prior to PVT-B completion, demonstrated significant short-term variations in participants’ feelings of sleepiness. Regardless of the shift worked, participants expressed increased feelings of sleepiness towards the end of the test day, most markedly between the third and fourth PVT-B tests. In contrast, no differences in KSS scores existed between the first (early morning) and final (early to late evening) PVT-Bs completed by workers while on days off or day shifts. This lack of difference is likely due to a low level of arousal experienced by workers during the early morning transition from sleep to wake (sleep inertia) (Blatter & Cajochen, 2007). Additionally, participants reported the greatest experience of sleepiness in the evening hours (6PM +) while on days off as well as during day shifts. Interestingly, the late evening is typically associated with increased vigor and performance due to normal fluctuations in circadian activity (Valdez, Ramirez, & Garcia, 2012). This finding may instead be a reflection of the prolonged time spent awake by participants or a phase-shift in circadian rhythmicity. However, while on night shifts participants' subjective sleepiness gradually increased following the second PVT-B test time (late evening) and peaked in the early morning hours (4AM - 8AM) – an outcome more representative of typical circadian variations. Furthermore, no correlation between reported subjective sleepiness on the KSS and performance on the PVT-B was observed in this sample. Though previous studies have demonstrated a relationship between subjective sleepiness and PVT performance, these studies were typically conducted in a controlled laboratory setting with young-adults (Horne & Burley, 2010) or entirely female samples (Kaida et al., 2006).

Participants' level of alertness was quantified using common PVT-B variables: simple RT and attentional lapses. Although compliance was low, about 50% throughout the study, enough data was collected to allow for within subject comparisons across the course of a typical day off or work shift (day or night) as well as over the course of several consecutive shifts. Participants maintained a consistent level of PVT-B performance during their days off (no significant variations in RT between test intervals) and also while working day shifts. However, workers' ability to preserve the same degree of alertness dissipated during the course of their night shifts. Performance peaked (fastest RTs) in the late evening of night shifts (between 8PM and 12AM) but continually declined as the shift progressed. By the early morning, when workers typically finished their shift and started their commute home (around 4-5AM), participants' RTs were significantly slowed. This finding indicates that participants' were experiencing decreased levels of alertness resulting in a diminished capacity to respond to stimuli. These results parallel the reports of greater frequencies of workplace accidents and higher rates of drowsy driving occurring in the early morning hours (Ftouni et al., 2013). Neither RT nor number of attentional lapses appeared to vary over the course of consecutive shifts.

Initially the significant decline in participants' alertness during night shifts does not appear to be the consequence of spending an extended amount of time awake prior to PVT-B completion. Though workers spent nearly 17 consecutive hours awake prior to completing the final PVT-B of their night shift, this duration of wakefulness did not significantly differ from the 15.3 hours participants' spent awake leading up to the final PVT-B of their day shift. However, it is worth noting that prolonged wake times in excess of 16 hours are associated with a linear increase in behavioural lapses and also an elevated likelihood for experiencing workplace accidents and/or adverse driving events (Åkerstedt, 1994; Rosa, 1995; Van Dongen et al., 2003). In contrast, workers' RTs were significantly faster during the second test interval of their night shifts despite spending nearly twice the amount of time awake compared to the same test interval (Test Time 2) on day shifts (11hrs, 45 mins and 6hrs, 20 mins respectively). Additionally, participants' PVT-B performance did not consistently correlate with wake time during days off or work days.

Alertness in this sample of miners does not seem to follow a dose-response curve during prolonged wakefulness; otherwise participants' PVT-B performance would have also deteriorated over the course of their day shifts. However, it is plausible that the dramatic rise and fall in participants' alertness over a night shift is indicative of an interaction between the two processes responsible for sleep regulation, Process S (homeostatic sleep drive) and Process C (circadian sleep drive) previously described by Borbély (1982). Hypothetically, during the beginning of a night shift (early evening) Process S would remain low and Process C would peak resulting in high levels of alertness. In contrast, as participants' reach the end of a night shift (early morning) Process S would be high and Process C will be at its nadir, in turn, impairing alertness and cognition. This model can also explain the consistent PVT-B performance observed during day shifts, Process C increases throughout the day ameliorating the decay in performance attributable to Process S.

Results of the Cosinor analyses indicated that only a third of the sample (37%) displayed variations in RT entrained to a circadian rhythm, none of whom demonstrated consistent circadian rhythms across all shift conditions. This finding seems anomalous as cognitive performance, especially alertness, is documented as following human circadian rhythms (Van Dongen & Dinges, 2005). In addition, these results suggest that the entirety of this sample are experiencing circadian disruption to some extent. However, we interpret the results from the Cosinor analyses cautiously due to the low compliance for PVT-B completion as well as the lack of evenly-spaced time intervals between data collection periods (e.g. every 4 hours).

Of the workers whose performance were synchronized to the circadian rhythm, one individual revealed an acrophase (peak time) during an unexpected time frame: approximately 9PM. The other six individuals presented acrophases at predictable times. Keeping in mind that the dependent variable used in the analyses was RT so the “peak” time reflects the slowest responses. Thus, it was unusual to observe a participants’ slowest RTs occurring at a time in which increases in performance are normally observed. This finding may reflect a phase-shift in this participant’s circadian rhythm, although it is impossible to determine whether the phase had been advanced or delayed. Although, previous studies suggest that circadian phase delays can be a consequence of night work (Lamond et al., 2003).

Typically CBT is entrained to the circadian rhythm, reaching its nadir in the early morning between 02:00 and 04:00, however no significant differences in CBT were observed between day shifts and night shifts in this sample. On the other hand, a significant negative correlation was observed between participants’ RTs and CBTs exclusively during day shifts. As a result, it is unknown whether the physiological nadir was totally absent due to disturbed circadian rhythms or whether it was simply missed following early termination of CBT data collection. Since workers leave work around 4-5AM after a night shift it is possible that a delayed phase-shift in circadian rhythms is preventing participants' lowest CBTs from being captured during data collection periods. Consequently, it is unclear whether this outcome further reflects a disruption in participants' circadian rhythms (whether a phase-shift or a total desynchronization) or an adaptation to night work. Ambient environmental temperatures were not correlated with participants' performance or CBT. This is likely due to the moderate temperature ranges in which participants were working.

4.1 Recommendations and Future Direction

Fatigue in the workplace is detrimental to the health and safety of workers, especially in industrial environments where myriad occupational hazards exist. It is the responsibility of both the employers and the workers themselves to create a safe environment to work in. The reduction of fatigue in workers can be facilitated at both the level of the individual as well as the corporate level through the implementation of strategies to aid in adapting to work schedules.

Shift workers are often unable to achieve sleep of adequate quality and duration so it is important for these individuals to make sleep a priority and to capitalize on existing rest opportunities. One way for workers to achieve better sleep is to develop good sleep hygiene (Jefferson et al., 2005; Mastin, Bryson, & Corwyn, 2006). Sleep hygiene refers to the range of adaptable, behavioural practices that are conducive for sleep (Todd & Mullan, 2013). Examples of good sleep hygiene include making the bedroom as restful as possible by eliminating light, noise, and other distractions; keeping a lower room temperature; going to bed at the same time each day; as well as avoiding stress and anxiety prior to bed time (American Sleep Disorders

Association, 1990). Maintaining proper sleep hygiene is a simple method to achieve better quality sleep, longer sleep duration, and increased daytime alertness (Mastin, Bryson, & Corwyn, 2006; Zarcone, 2002). Furthermore, practicing good sleep hygiene is reportedly facilitates adjustments to irregular work schedules (Costa, 2003).

Researchers suggest that several of the consequences linked to fatigue and sleep loss may be alleviated if adaptation to irregular shift can be achieved (Burgess, Sharkey, & Eastman, 2002; Gibbs et al., 2002; Lamond et al., 2003). Previous studies have shown that several consecutive shifts of the same type (e.g. night shift) promote an adaptation to work schedules with subsequent improvements in sleep duration and sleep quality; alleviating sleep debt and symptoms of sleep disorders; as well as increases in cognitive performance (Gibbs et al., 2002; Ferguson et al., 2012; Lamond et al., 2003). Laboratory studies conducted by Lamond and colleagues (2003, 2004) found that after seven nights of a simulated night work protocol, mean relative performance on a reaction time task significantly improved across shifts. Also, field studies of oil-rig workers and individuals working in the North Sea indicated performance and circadian adaptation to night shifts after seven consecutive shifts (Bjorvatn et al., 2006; Gibbs et al., 2002). However this adaptation was not observed in Australian miners after working the same number of successive night shifts (Ferguson et al., 2012; Paech et al., 2010).

Ferguson and colleagues (2012) proposed that the absence of circadian rhythm adaptation (measured via melatonin concentration in saliva) in the mining population may be due to the exposure of environmental light before and after work shifts. These findings parallel the remarks made by Gibbs and colleagues (2002), concluding that adaptation is more likely to occur when exposure to light is minimal or absent. Due to the role that light plays in regulating circadian rhythms, light exposure at irregular times can lead to maladaptation of this biological cycle

(Ferguson et al., 2012). Accordingly, future studies would benefit from monitoring participants' exposure to both artificial (indoor) and environmental (outdoor) light sources, as well as providing an objective measure of circadian adaption (e.g. salivary or urinary melatonin levels).

4.2 Limitations and Considerations

This study is not without limitations. Although exploratory in nature, this study required an extensive time commitment (up to 30 days) from participants. In addition, a large proportion of the data collection was unsupervised, requiring participants to self-motivate. Although this method eliminates the need for participants to alter their daily activities (e.g. not requiring participants to spend time in a lab or meet with researchers), it did create a large degree of variation (18-91%) in PVT-B test compliance.

Furthermore, with the difficulty in recruiting viable participants (candidates were also required to meet stringent inclusion/exclusion criteria) all data sets, even partial ones, were included in relevant statistical analyses. However, care was taken to remove any extreme outliers from data sets so not to confound the results. In addition, numerous statistical analyses were performed as part of this exploratory study, resulting in an increased experiment-wise alpha. Consequently, the probability of incorrectly rejecting a true null hypothesis (committing a Type 1 error) during these analyses also increased. Finally, it is of note that the results of these analyses will not be applicable to more general mining samples (e.g. female workers, young workers, non-shift workers) due to the strict inclusion criteria met by participants.

Although pre-existing sleep pathology was a criterion for exclusion from this study it is possible that some study participants may be suffering from an undiagnosed sleep disorder. Reportedly, between 18-24% of middle-aged adults, the age group of interest in this study, may be living with an undiagnosed sleep pathology (Finkel et al., 2009; Young et al., 1993). For example, in a study following 195 shift-workers who worked in an underground mine, 15 of the 21 (71.4%) severely fatigued workers, determined by subjective questionnaires, suffered from an underlying sleep pathology (OSA, bruxism, or periodic limb movements disorder) (Hossain et al., 2003). Due to sleep disorders eliciting a variety of sleep disturbances (e.g. difficulties initiating or maintaining sleep), in turn decreasing sleep quality and duration, the results of this study could potentially be confounded if any of the individuals in this sample suffer from an undiagnosed sleep disorder.

Excessive drug and/or alcohol use were both exclusion criteria for this study, however participants were not asked to abstain from the use of their regular prescription medication(s) or from the moderate consumption of alcoholic or caffeinated beverages during study enrollment (whether work days or days off). Though both caffeinated and alcoholic beverages influence sleep quality (Roehrs & Roth, 2001) and cognitive performance (Lamond et al., 2004; Pandi-Perumal et al., 2006), the aim of this study was not to manipulate participants' activities but to gain a true representation of the behaviours that are typical of the individuals in these jobs. Although due to this study's within-subjects design and the duration of the data collection period, the effect of these activities on the overall findings of this study should be minimal.

Also of note is that participants' chronotypes were not taken into consideration for this study. Chronotype, whether morning type, evening type, or intermediate type, reportedly influences circadian-driven activities such as the sleep-wake cycle (wake and bed times) and also peaks in body temperature (Horne & Östberg, 1976). In addition, chronotype has also been associated with individual differences in peak performance times (cognitive and physical) (Valdez, Ramirez, & Garcia, 2012). For example, morning types display phase-advanced sleep-wake cycles and perform best in the morning hours (Kerkhof & Van Dongen, 1996). An individual's chronotype can be determined using a subjective questionnaire (Horne & Östberg, 1976). Although it is plausible that the workers in this sample are of the "evening type" due to their continued ability to maintain night work schedules. Subsequently, differences in participants' chronotypes could cause the findings of this study to be less generalizable to other mining samples (e.g. those working permanent day shift schedules).

Also, no measure of participant work load was collected during the study. Metabolic heat load is an internal heat factor that contributes to the heat stress, and subsequent heat strain, a worker may experience. Work load is an important factor in determining heat stress especially when an individual is exerting themself; consequently, it would have been advantageous to have participants complete a list of job duties which they perform during a typical shift. An objective measure of work load, such as heart rate, would also have been beneficial in order to further quantify participants' metabolic heat load.

Finally, a degree of error exists in the calculated WBGTs reported in this study, in turn causing the WBGT to be underestimated and therefore lower than the true value. The equation used to derive environmental WBT (an element of the WBGT) from measures of RH and T assumes the standard atmospheric pressure observed at sea level (101.325 kilopascals). Though atmospheric pressure was not measured during the time of environmental data collection, atmospheric pressure increases as a function of depth. Consequently, underground mines with an altitude below that of sea level will have a greater atmospheric pressure resulting in an increase in the observed WBT and WBGT values (measures contingent on air temperature, air velocity, and air pressure).

4.3 Conclusion

The individuals in this sample of middle-aged, male underground miners suffer from chronic sleep deprivation (SE $\leq$85%, TST $\leq$ 6.3hrs) and, potentially, circadian rhythm disruption. Despite their consistently poor sleep these individuals are able to maintain their level of alertness while working day shifts but not night shifts. The increases in RT observed during night shifts may be a consequence of reduced sleep quality and duration or a lack of circadian adaptation rising from working rotating shifts. However, variations in night-time RTs can be explained by the interaction between the homeostatic sleep drive and the circadian sleep drive, making a case for the presence of an intact circadian rhythm in these individuals. Alternatively, only a third of participants displayed RTs that corresponded to a typical 24-hr circadian pattern, suggesting that most individuals may be experiencing fluctuations in alertness lacking circadian influence or adaptation. In addition, a strong, inverse relationship between RT and CBT was present in workers during day shifts but was absent during night shifts, another indication that participants are not able to adapt to night work. Without an objective measure of circadian rhythmicity it is impossible to determine whether these individuals are experiencing circadian rhythm disruption or not. What is known for certain is that these individuals are likely unable to obtain restorative sleep and will continue to accrue an increasing sleep debt, care must be taken to prevent these individuals from posing an occupational health and safety concern.

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Appendix A

Laurentian University Research Ethics Board Approval

LaurentianUniversity
UniversitéLaurentienne

APPROVAL FOR CONDUCTING RESEARCH INVOLVING HUMAN SUBJECTS
Research Ethics Board – Laurentian University

This letter confirms that the research project identified below has successfully passed the ethics review by the Laurentian University Research Ethics Board (REB). Your ethics approval date, other milestone dates, and any special conditions for your project are indicated below.

TYPE OF APPROVAL	**New**	X	**Modifications to project**		**Time extension**	

Name of Principal Investigator and school/department	Dr. Glenn Legault and Alex Clement (Psychology – LU)
Title of Project	*Cognitive Consequences of Sleep Deprivation, Shift Work, and Heat Exposure for Underground Miners*
REB file number	2012-03-01
Date of original approval of project	April 26th 2012
Date of approval of project modifications or extension *(if applicable)*	
Final/Interim report due on	December 31st 2012
Conditions placed on project	Final or interim report on December 31st 2012

During the course of your research, no deviations or changes to the protocol, recruitment or consent forms may be initiated without prior written approval from the REB. If you wish to modify your research project, please complete the appropriate REB form.

All projects must submit a report to REB at least once per year. If involvement with human participants continues for longer than one year (e.g. you have not completed the objectives of the study and have not yet terminated contact with the participants, except for feedback of final results to participants), you must request an extension using the appropriate REB FORM.

In all cases, please ensure that your research complies with the Tri-Council Policy Statement (TCPS). Also please quote your REB file number on all future correspondence with the REB office.

Congratulations, and best of luck in conducting your research.

Jean Dragon Ph.D. (Ethics officer LU) for Susan James Ph.D.
Acting Chair of the *Laurentian University Research Ethics Board*
Laurentian University

Appendix B

Participant Sleep Log

Daily Sleep Log

LaurentianUniversity UniversitéLaurentienne

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Midnight							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM							
9:00 AM							
10:00 AM							
11:00 AM							
12:00 PM							
1:00 PM							
2:00 PM							
3:00 PM							
4:00 PM							
5:00 PM							
6:00 PM							
7:00 PM							
8:00 PM							
9:00 PM							
10:00 PM							
11:00 PM							
Midnight							

Please indicate when you:

* Were sleeping
* Were working (indicate OT for overtime)
* Exercised (and what type of exercise)
* Had meals (breakfast, lunch, snacks, etc)

Daily Sleep Log - Page 2

LaurentianUniversity UniversitéLaurentienne

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Date							
Wake time							
How do you feel today? **1**: Poorly rested **2**: Somewhat rested **3**: Well rested **4**: Completely rested							
Number of caffeinated drinks?	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:
Level of intoxication **1**: Sober **2**: Able to drive **3**: Unable to drive **4**: Extremely intoxicated	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:	AM: Noon: PM:
Did you work today? (Day or night shift? For how many hours? Did you take any breaks and for how long?)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)	Day / Night Hours: # of Breaks: Average Break (mins)
Bedtime							
How long did it take you to fall asleep?							
How many times did you wake up during the night? How long were you awake?							
Did you take any prescription or non-prescription drugs before bed? (What? How much?)							

Appendix C

Demographics Questionnaire

Laurentian University Université Laurentienne

Demographics Questionnaire

Name:_________________________ **Date:**_______________ **Study ID:**______

Please read each question carefully, and answer every item by picking the most appropriate answer. Information in this questionnaire is for Laurentian University research purposes only and will be kept confidential.

1) Gender: Male or Female
2) Date of Birth (mm/dd/yy): _____________________
3) Primary language (English, French, etc): ____________________________
4) Handedness (right or left handed): ________________________
5) Height (cm): ________________________
6) Weight (kg): ________________________
7) How many children under 5 years old live in your household? _________
8) Are you currently on any medication that may affect your sleep? **Yes or No**

   If yes, please specify: ____
9) Has a Doctor diagnosed you with a sleep or mood disorder? **Yes or No**

   If yes, please specify: ____

21) Do you take any prescription drugs or non-prescription drugs prior to going to bed (including sleeping pills)? **Yes or No**

If yes, please specify: ____

22) Have you gained or lost weight in the last 5 years?

[ ] Gained _________ (in kilograms) [ ] Lost _________ (in kilograms)

23) Has anyone ever told you that you snore? **Yes or No**

24) Has anyone ever told you that you talk in your sleep? **Yes or No**

25) Has anyone ever told you that you kick your feet in your sleep? **Yes or No**

26) Has anyone ever told you that you choke, gasp, or hold your breath while sleeping? **Yes or No**

27) How often do you think you snore?

[ ] Never [ ] Rarely [ ] Often [ ] Always

28) How often do you think that you kick your feet (run) in your sleep?

[ ] Never [ ] Rarely [ ] Often [ ] Always

29) How often do you think you choke, gasp, or hold your breath while sleeping?

[ ] Never [ ] Rarely [ ] Often [ ] Always

30) How often do you think you grind your teeth in your sleep?

[ ] Never [ ] Rarely [ ] Often [ ] Always

31) How often do you think you sleep walk?

[ ] Never [ ] Rarely [ ] Often [ ] Always

32) How often do you have other unusual behaviours in your sleep (for example, acting out dreams)?

[ ] Never [ ] Rarely [ ] Often [ ] Always

33) What position do you most commonly sleep in?

[ ] On my back [ ] Left side down

[ ] Right side down [ ] On my stomach

34) How well do you sleep away from home?

[ ] Better [ ] Same [ ] Worse

35) If you have a pet (dog, cat, etc), do they normally sleep in the same room as you at night? **Yes or No**

36) Have you slept in the same room/bed as someone else in the last year? **Yes or No**

37) How often do you sleep with someone (or have a pet) that is restless (moves around) while you are sleeping?

[ ] Never [ ] Rarely [ ] Often [ ] Always

38) How often do you sleep with someone (or have a pet) that makes noise while you are sleeping?

[ ] Never [ ] Rarely [ ] Often [ ] Always

39) What is the **average** number of nights per week that you wake up at least once mid-sleep (out of 7 nights): ____________________ nights

40) What is the **average** number of times that you wake up per night/sleep:

______________ times

41) When you wake up mid sleep (during the night), how long is it until you fall asleep again? ________________ minutes

42) After waking up, how many minutes on average do you stay in bed before getting out of bed for the day?

[ ] 15 minutes or less [ ] 16-30 minutes

[ ] 31-60 minutes [ ] more than 60 minutes

43) What is the likelihood that you would sleep in if you did not use an alarm clock or have someone/something wake you up?

[ ] Not at all likely [ ] Somewhat likely

[ ] Quite likely [ ] Extremely likely

44) How often do you feel refreshed when you wake up for the day?

[ ] Never [ ] Rarely [ ] Often [ ] Always

45) In a normal week, how many days would you have a nap (out of 7):

_________________ days

46) On average, how long would you nap for: ____________________ minutes

Appendix D

Pittsburgh Sleep Quality Index

Name:____ Date: ________________

Pittsburgh Sleep Quality Index (PSQI)

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

1. During the past month, what time have you usually gone to bed at night? __________________
2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night? _________
3. During the past month, what time have you usually gotten up in the morning? __________________
4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.) __________________

5. During the past month, how often have you had trouble sleeping because you…	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
a. Cannot get to sleep within 30 minutes				
b. Wake up in the middle of the night or early morning				
c. Have to get up to use the bathroom				
d. Cannot breathe comfortably				
e. Cough or snore loudly				
f. Feel too cold				
g. Feel too hot				
h. Have bad dreams				
i. Have pain				
j. Other reason(s), please describe:				
6. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?				
7. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?				
	No problem at all	Only a very slight problem	Somewhat of a problem	A very big problem
8. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?				
	Very good	Fairly good	Fairly bad	Very bad
9. During the past month, how would you rate your sleep quality overall?				

	No bed partner or room mate	Partner/room mate in other room	Partner in same room but not same bed	Partner in same bed
10. Do you have a bed partner or room mate?				
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
If you have a room mate or bed partner, ask him/her how often in the past month you have had:				
a. Loud snoring				
b. Long pauses between breaths while asleep				
c. Legs twitching or jerking while you sleep				
d. Episodes of disorientation or confusion during sleep				
e. Other restlessness while you sleep, please describe:				

Appendix E

Epworth Sleepiness Scale

THE EPWORTH SLEEPINESS SCALE

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

0 = no chance of dozing
1 = slight chance of dozing
2 = moderate chance of dozing
3 = high chance of dozing

SITUATION	CHANCE OF DOZING
Sitting and reading	____________
Watching TV	____________
Sitting inactive in a public place (e.g a theater or a meeting)	____________
As a passenger in a car for an hour without a break	____________
Lying down to rest in the afternoon when circumstances permit	____________
Sitting and talking to someone	____________

Sitting quietly after a lunch without alcohol	____________
In a car, while stopped for a few minutes in traffic	____________

To check your sleepiness score, total the points . Check your total score to see how sleepy you are.

Appendix F

Karolinska Sleepiness Scale

Karolinska Sleepiness Scale

Rate your current level of sleepiness

1 = extremely alert

2 = very alert

3 = alert

4 = rather alert

5 = neither alert nor sleepy

6 = some signs of sleepiness

7 = sleepy, but no effort to keep awake

8 = sleepy, some effort to keep awake

9 = very sleepy, great effort to keep awake

10 = extremely sleepy, falls asleep all the time

Appendix G

Hydration Questionnaire

How many servings of fluid (water, coffee, sugary drinks but NOT ALCOHOL) have you consumed in the last 5 hours? One serving = 1 cup/250 mL (ex. a large Tim Hortons coffee is 2 servings).

- 0
- 1
- 2
- 3
- 4
- 5+

Appendix H

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