UNDER THE INFLUENCE: AN EVALUATION OF THE IMPACT FATIGUE HAS ON COGNITIVE FUNCTION OF FIREFIGHTERS WORKING 24 AND 48-HOUR SHIFTS

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Abstract: The purpose of this research was to understand the impact fatigue has on cognitive function of firefighters working 24 and 48-hour shifts and to observe the extent of recovery that occurs between shift rotations. Data collected via actigraph, daily journal, and psychomotor vigilance tests were combined using date/time stamps to evaluate cognitive performance at various times of the day. Variables included demographic data, biometric data, subjective ratings of fatigue and sleepiness, objective measures of cognitive performance (PVT response times and errors), workload, sleep quantity and quality, and whether the participant was on or off shift. During this study participants slept an average of 5.3 hours while on shift and an average of 5.9 hours while not on shift. Results indicate there is a significant difference in the quantity of sleep obtained on and off shift (average of 32 minutes), but there is not a significant difference in the mean values of the cognitive performance between on and off shift. The mean value of cognitive performance both on shift (M=460ms) and off shift (M=456ms) is near the cutoff for what is considered normal response time (500ms). Additionally, an average of 25% (Range 22-27%) of the participants had mean response times greater than 500ms at all times of the day, both on and off shift. There were no significant differences observed in the objective measures of cognitive performance between groups with different years of experience, nor between groups that worked 24- or 48-hour shifts. Significant correlations between subjective fatigue ratings and objective measures of cognitive performance were only observed at noon and were inconsistent at all other times of the day. They reported feeling less fatigued and sleepy at noon, even though the objective measures of cognitive performance indicate a steady decline from the beginning of the day to the end of the day. Together these results may indicate firefighters are chronically fatigued, experiencing cognitive performance only slightly better than someone who is impaired by alcohol consumption, they may not be able recognize this impairment, and their performance is not improving on days off. Implementation of a fatigue management plan is recommended.

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CHAPTER I

UNDER THE INFLUENCE: AN EVALUATION OF THE IMPACT FATIGUE HAS ON COGNITIVE FUNCTION OF FIREFIGHTERS WORKING 24 AND 48-HOUR SHIFTS

Introduction to the Problem

Fatigue is pervasive in today's society, which requires 24-hour a day, 7-days per week access to services. Fatigue can have an impact on both physical and mental performance. This impact is especially relevant to the fire service, where a speedy and high-quality response is essential at all hours of the day and night, regardless of staffing, funding, or other circumstances that may influence resources. In this profession, failure to perform as expected may result in injury or life-threatening consequences. Additionally, fatigue has been found to have short-term effects such as a propensity for errors and/or injuries, as well as to have chronic health effects on the body. A review of firefighter injury and illness data suggests fatigue is having a profound impact on the fire service.

According to the Bureau of Labor Statistics (BLS), firefighters experience more on-the-job injuries than any other occupation. A 2011 BLS report that specifically focused on firefighters, indicated that non-fatal injuries in firefighters was 47.2 per 10,000 full-time workers, compared with 117.3 for all other occupations (Bureau of

Labor Statistic, 2013). Fatigue contributes to these types of injuries. A report in EHS Today, indicates “an overexertion injury happens when a worker becomes fatigued or performs a job where the human body's capacity to complete the task was not sufficiently considered” (Nighswonger, 2001). Though there is not a more current comparison to other occupations, a 2019 NFPA report confirmed overexertion is still the most common cause (39%) of on-the-job injuries for firefighters (Campbell & Evarts, 2020).

In addition to physical injuries that may occur, frequent and prolonged exposure to fatigue exacerbates health risks. In fact, detrimental health effects may have an even more profound impact than the risk of physical injury. According to the U.S. Fire Administration (USFA) summary report, between January 2009 and December 2018, 323 firefighters died in the line of duty. Almost half of those deaths (47.8%) were due to heart attack (USAF, 2019). Heart attacks have been the number one killer of firefighters in the line of duty for decades (Poston et al., 2011). Acute onset events, however, are not the only health issue that should be of concern.

Persistent exposure to fatigue may also lead to chronic health effects that decrease the quality of life until the firefighter eventually succumbs to illness. Sleep deprivation and working against the natural circadian rhythm (working at night) disrupts the body’s natural hormonal and endocrinological functions resulting in increased risks of obesity, gastro-intestinal disorders, cardiovascular disease, cancer, sleep disorders (Barger, Lockley, Rajaratnam, & Landrigan, 2009; Billings & Focht, 2016; Elliot & Keuhl, 2007), and mental health issues such as depression, PTSD, and suicide (Billings & Focht, 2016; Elliot & Keuhl, 2007; Katsavouni, Bebetsos, Malliou, & Beneka, 2016). As sleep debt increases, so too does the risk of experiencing one or more of these aliments.

Firefighters have a higher rate of obesity than does the general public. Poston et. al, (2011) report a range between 73 to 88 percent of firefighters are overweight or obese. A poor diet may contribute to this condition; however, firefighters are at a greater risk because fatigue leads to poor functioning of the endocrine system. Disrupting the circadian rhythm, especially with sleep restriction, results in an imbalance between the hormones ghrelin (which stimulates appetite, especially for carbohydrates and sugars) and leptin (which stimulates a feelings of fullness) (Copinschi, 2005; Knutson & Van Cauter, 2008; Spiegel, Tasali, Penev, & Van Cauter, 2004). This causes the misperception that one is hungry, when in fact there is no physical need for caloric intake. Spiegel, et. al, (2004) found a 24 percent increase in hunger and a 23 percent increase in appetite among participants whose sleep was restricted to four hours. This can lead to excessive and unnecessary eating. Furthermore, obesity can lead to, or worsen other health conditions such as cardiovascular disease (Spiegel et al., 2004), diabetes (Knutson & Van Cauter, 2008; Spiegel et al., 2004), and high blood pressure (Choi, Schnall, & Dobson, 2016).

Similarly, the digestive system also works on a cyclical schedule, which when interrupted results in breakdown of function (Elliot & Keuhl, 2007). Alteration of sleeping and eating habits result in the disruption of digestive enzyme secretion, leading to a six-fold increase in gastrointestinal disorders, such as peptic ulcers, indigestion, diarrhea and constipation (Orr & Chen, 2005). In a study of South Korean firefighters, 37.9 percent showed Functional Gastrointestinal Disorders with heart burn being the most common (Jang, Ryu, Choi, & Lee, 2016). Though these disorders are not likely to lead to death, they decrease the quality of life for those who suffer from the conditions. Additionally, these conditions may interrupt sleep and initiate a self-perpetuating cycle of decreased sleep and increased symptoms.

Firefighters experience increased risk of suffering from sleep disorders. These disorders exacerbate fatigue by decreasing the quality of sleep obtained (Barger et al., 2009). One study found that 37 percent of firefighters are at high risk for common sleep disorders such as obstructive sleep apnea (OSA) (Czeisler, Barger, & O'Brien, 2019). Shockingly, 83 percent of those who screened positive for sleep disorders in this study were undiagnosed and therefore untreated (Czeisler et al., 2019). This is especially concerning because disorders such as OSA are associated with loud snoring. Meaning that the disorder will cause detrimental effects for the firefighter, but may also have implications for coworkers, who in most fire stations sleep in dormitory style rooms. Experiencing sleep disorders doubles the risk of these firefighters being involved in motor vehicle accidents and having cardiovascular disease and/or diabetes (Czeisler et al., 2019). Likewise, it more than triples the chance of having depression or anxiety (Czeisler et al., 2019).

Fatigue reduces the body's ability to cope with stress and increases the risk of mental health disorders such as depression, anxiety, and PTSD. Research results have been inconsistent in identifying the direction of the relationship between sleep disorders, depression, and anxiety (Aderka, Foa, Applebaum, Shafran, & Gilboa-Schechtman, 2011; Babson & Feldner, 2010; Breslau, 2002). There is, however, no argument that these conditions are highly correlated. Additionally, research indicates that sleep disturbances when combined with depression and anxiety significantly increase the risk of experiencing PTSD (Borders, Rothman, & McAndrew, 2015; Irwin, Konnert, Wong, & O'Neill, 2014; Straud, Henderson, Vega, Black, & Van Hasselt, 2018). Approximately 22 percent of firefighters experience PTSD, a rate that is considerably higher than the general population (4.5%) (Corneil, Beaton, Murphy, Johnson, & Pike, 1999; Gramlich & Neer, 2018).

Additionally, cancer is perhaps one of the most prevalent health risks firefighters face. NIOSH tracked cancer amongst over 30,000 career firefighters between 1950 and 2010. Their results were published in a 2016 report, which indicated that cancer diagnosis for firefighters was 9% higher than the general population and cancer deaths were 14% higher than the general population (Shaffer, 2019). Furthermore, in 2007, an International Agency for Research on Cancer (IARC) work group concluded, based on evidence, that "shift work involving circadian rhythm disruptions is probably carcinogenic to humans" (Straif et al., 2007, p. 1065). At the same meeting they concluded that firefighter respiratory exposures to hazardous chemicals in smoke is "possibly carcinogenic to humans" (Straif et al., 2007). Though there have been numerous studies conducted on each of these factors individually, no study was found that examined the synergistic effects of the combined exposure. Cancer has now surpassed heart attacks as the number one (non-line-of duty) killer of firefighters (Shaffer, 2019).

Fatigue is taking a costly toll on U.S. firefighters. "The cost of firefighter injury [and illness] is estimated to range between $1.6 billion and $5.9 billion annually. This cost result in a loss equivalent to approximately $50,000 to $200,000 per fire department per year or $1,500 to $5,500 per firefighter per year"(Butry, Webb, Gilbert, & Taylor, 2019). The fiscal management of the fire service is the responsibility of local municipalities, which may be financially strapped (Meyer, 2003). Inadequate funding often leads to insufficient staffing (Hensler, 2011). Reduced resources, especially staffing, increases the workload on all remaining firefighters, thereby increasing fatigue and escalating the risk of injury and illness. As firefighters are removed from duty due to injury, illness, or the choice to leave the profession, this further escalates fatigue for those remaining. The issue creates a self-perpetuating cycle of continually increasing demand coupled with a continually decreasing resources. Identifying the factors that cause fatigue and implementing effective intervention plans is the first step to break the cycle. Reducing fatigue is an effective means of reducing the overall operating cost of the fire service and potentially relieving some of the fiscal strain on local municipalities, and subsequently providing additional resources.

Fatigue Risk Factors

Fatigue is a complex, multifaceted concept that is difficult to define and measure because it cannot be directly observed (Williamson et al., 2011). It may manifest as either a physical impartment (feeling of tiredness, physical weakness, inability to maintain physical workload) or a mental impairment (feelings of stress, slowed reaction time, reduced ability to think clearly, impaired decision-making or problem solving, etc.). Often a person experiencing fatigue will experience both physical and mental effects simultaneously.

The symptoms of fatigue arise from internal and/or external stressors which exceed the body's resources for compensation (Aaronson et al., 1999). Stressors, or risk factors, that increase the risk of fatigue (both physical and cognitive) on the job include (National Safety Council, 2019b):

1. **Shift Work** (any non-day shift work) – Changing shifts or extended shifts interfere with the body's natural sleep schedule. Firefighters work 24-hour shifts (or longer). Although they are not expected to stay awake for a full 24-48 hours, they are required to respond to calls regardless of the time of day or night. At busier stations, sleep is interrupted throughout "normal" sleep hours. There are also those occasions on which the response may take all night or the firefighter responds to call after call and is not able to sleep at all during the shift.

2. **High-Risk Hours** (early morning or late-night) – Due to the extended shifts that firefighters work, they may be exposed to both early morning and late-night work on each shift.

3. **Demanding Jobs** (jobs that require sustained attention or are physically or cognitively demanding) – Firefighter jobs duties "include fire prevention, emergency medical service, hazardous material response, search and rescue, and disaster assistance (Bureau of Labor Statistics, 2013)." These tasks are both physically and cognitively demanding and are frequently conducted while wearing 45 pounds or more of equipment (Kirshman, 2004).

4. **Long Shifts** (working 10 or more hours in a single shift) – Firefighters work a minimum of 24 hours consecutive, and may work as much as 48 hours in a single tour of duty.

5. **Long Weeks** (working over 50 hours in a week) – 56 hours is the average work-week for firefighters. However, due to many departments being "severely understaffed," firefighters may be required to work as much as 112 hours in a single week (Hensler, 2011).

6. **Sleep Loss** (seven to nine hours of sleep per 24-hour period is recommended) – Due to work demands and continuous alerts, firefighters may get little, to no sleep within a 24-hour period. The sleep they do get may be fragmented and of such low quality that it does not allow the body to recuperate.

7. **No Rest Breaks** (physical recuperation can occur with as little as a ten-minute break. State laws differ, but every state requires a minimum of 10-15 minutes rest break every four hours (U.S. Department of Labor, 2019) – Depending on call volume, firefighters may or may not be exposed to this risk factor on every shift.

8. **Quick Shift Return** (employees need at least 12 hours between shifts to recover) – When firefighters are required to work overtime, or if they work for a department that has 48-hour shifts, there is no recovery time for a minimum of 48 hours. Additionally, no study has been conducted to determine adequate recovery time for firefighters.

9. **Long Commutes** (what constitutes a long commute is not defined, however time spent on driving following a shift reduces recovery time available). – This is an individual factor that affects some, but not all, firefighters.

With each additional risk factor, the effects of fatigue are compounded. This is particularly true for those exposed to these factors simultaneously for an extended period of time, such as firefighters. Firefighters are among less than five percent of U.S. workers who are exposed to between seven and nine of these risk factors every time they go to work.

Several of the risk factors described above are related to loss of sleep. Though there are a variety of schedules used within the fire service, in the U.S. most fire departments use a 24-hour (24 hours on 48 hours off) or 48-hour shift (48 hours on 96 hours off). The 24-hour shift is most prevalent (Elliot & Keuhl, 2007). These shift scheduling practices may contribute to sleep-related fatigue by restricting sleep opportunities, reducing the quality of sleep, disrupting the circadian rhythm, and working against the body's homeostasis.

Homeostasis is the body's process of achieving internal stability (appropriately regulated temperature, hormone levels, etc.). There are a variety of processes that are involved in the overall stabilization of the human body, but for the purpose of this study the homeostasis process that is most relevant is the regulation of melatonin (responsible for feelings of sleepiness) and cortisol (responsible for feelings of alertness). There is some variation in individuals, but on average, the body stops producing melatonin and begins producing cortisol around 06:00-07:00. At this point the melatonin in the body begins decreasing and cortisol increases until it reaches a peak around 09:00-10:00. For well rested, healthy adults, wakefulness is then sustained throughout the day as the level of cortisol in the body slowly decreases, with only slight increases occurring around meal times (Fahey & Zee, 2020). The body begins producing melatonin again around 20:00, it reaches its peak around 01:00-03:00, while cortisol reaches its lowest point around midnight. After reaching its peak, the melatonin level in the body slowly declines until it reaches its lowest point around 06:00-07:00 when the body once again starts producing cortisol. This hormone cycle works in tandem with the biological sleep clock.

The term circadian rhythm refers to a variety of twenty-four hour cycles the body goes through. The cycle most often associated with the term is the sleep/wake cycle, or biological sleep clock. This is an internal system which regulates sleep. "This internal regulation is influenced by the external environment, and that cycle can be shifted, shortened/ lengthened and reset (termed entrainment) by external cues, such as variation in sunlight and activity patterns" (Elliot & Keuhl, 2007, p. 3).

Sleep is obtained in consecutive cycles that each consist of four stages (Suni, 2021). Stage one lasts approximately 1-5 minutes, it is non-REM (NREM) sleep, and is often referred to as the dozing off stage. Stage two lasts approximately 10-25 minutes during the first cycle and may extend up to 60 minutes in subsequent cycles. This stage is also NREM sleep and is characterized by a drop in body temperature, a decrease in breathing and heart rate, and the muscles relaxation. Stage three is also NREM sleep and is referred to as deep sleep. This is the stage in which to body performs repair functions (Yordanova, Kolev, Wagner, & Verleger, 2010). The first cycle of stage three will typically last approximately 20-40 minutes, with subsequent cycles getting shorter. During this stage body temperature, muscle tone, breathing and heart rate further decrease. During the fourth stage of sleep rapid eye movement (REM) begins, this is the stage in which dreams occur. This stage lasts approximately 10-60 minutes and is characterized by an increase in brain wave activity (Suni, 2021). This is the stage that is associated with cognitive function. During REM sleep the brain consolidates and stores information learned during the day (Ellenbogen, Payne, & Stickgold, 2006). This process is necessary for recall and application of declarative and procedural memories. This stage typically cannot be reached with less than 90 minutes of sleep (Suni, 2021).

A total sleep cycle, which is ideally 7-9 hours (Lui et al., 2016), will consist of four to six cycles through these sleep stages (Suni, 2021). When a stage of sleep is interrupted, the body does not return to that stage, but rather the entire cycle must start over. For this reason, when sleep is interrupted multiple times, the body may have difficulty conducting repair functions and storing information learned prior to that sleep cycle. This results in physical and cognitive detriments.

Humans are diurnal, as opposed to nocturnal. This means our natural processes are geared toward being awake during the day and asleep at night (Elliot & Keuhl, 2007). As with the homeostasis cycle, the timing of this cycle varies person to person, with most people beginning to feel drowsy shortly after sun down. The biological sleep clock is significantly influenced by exposure to light (Fahey & Zee, 2020). Because of this process, not all sleep is equal (Diez et al., 2020; Elliot & Keuhl, 2007). Greater quality sleep is typically obtained at night. Conversely, being awake during that time has greater influence on both physical and cognitive performance. Furthermore, exposure to light during the time when the body is routinely sleeping disrupts the circadian rhythm and can cause a phase shift (Fahey & Zee, 2020). This means the individual may have a harder time falling asleep at a routine time. Continued exposure to light during routine sleep time will cause an increased drive for the body to shift the sleep phase and cause further disruption of the circadian rhythm. The body's natural rhythm attempts to accommodate the interruptions by moving the sleep cycle forward, so the routine sleep time will be later.

Due to the body's drive for homeostasis and the biological sleep clock, firefighters may experience increased disruption of sleep prior to and during their shift. Shifts typically begin at either 07:00 or 08:00, which requires the firefighter to wake up 1-2 hours earlier depending on commute time (potentially even earlier for very longer commutes). Waking up prior to sunrise disrupts the body's natural sleep cycle. This may lead to firefighters showing up for work in a slightly sleep deprived state, that continues to worsen as the shift continues (Peterson, 2016). There are variations among individuals, but on average adults are at the lowest level of alertness between 03:00-07:00 due to the levels of melatonin in the system and the biological drive to sleep during this time. This is the time period in which firefighter are preparing for and driving to work. Alertness peaks at approximately 09:00-10:00. Under normal (non-fatigued) circumstances wakefulness is then maintained throughout the day, however many people, especially those who are already suffering from sleep debt, will feel a decrease in wakefulness between 13:00-15:00 (Suni, 2021). Some fire departments allow napping (schedule permitting), around this time, however many have policies that prevent napping prior to 17:00 (Peterson, 2016). Additionally, while on duty sleep may be (and often is) restricted or interrupted during routine sleep hours (approximately 22:00 and 07:00) due to emergency response calls (Peterson, 2016). In most stations, everyone is awakened by the emergency tones each time a response is required, regardless of whether they need to participate in the response or not. As mentioned earlier, exposure to light during this time may make it more difficult to return to sleep after waking. The schedule and demands of the job may therefore, lead to continually increasing sleep debt throughout the remainder of the shift.

Disruptions to sleep or sleep patterns can lead to performance detriments (Rudin-Brown, Harris, & Rosberg, 2019). Firefighter job duties are intensely physically demanding, but they require far more than simple brute strength (Hensler, 2011). They also require a high level of cognitive function for tasks such as rapid response, decision-making, problem solving, effective communication, interpretation of signs, symptoms, and signals from a variety of sources, and a whole host of other activities which are mentally demanding. Fatigue impairs both physical and cognitive abilities, resulting in decreased attention and cognitive function, slower reaction time, and reduced stamina needed to properly fulfil job duties. These types of impairment can increase risk for the firefighter, their co-workers, and those whom they are treating during medical calls, as well as reduce effectiveness of physically demanding jobs such as fighting fires and conducting rescue operations.

Studies have shown that loss of sleep can impair cognitive abilities in much the same way as alcohol intoxication (Arnedt, Owens, Crouch, Stahl, & Carskadon, 2005; Dawson & Reid, 1997; Roehrs, Burduvali, Bonahoom, Drake, & Roth, 2003). Research indicates that losing two hours of sleep from the recommended eight hours, results in performance equivalent to a person who has drank two to three beers (Roehrs et al., 2003). Additionally, studies have indicated that fatigue in those on-call for 24 or more hours results in performance similar to 0.04-0.05% blood alcohol level (Arnedt et al., 2005). This effect was even more drastic in those who sustain wakefulness for an entire 24-hour period. Their performance was found to be equivalent to 0.10% blood alcohol level (Dawson & Reid, 1997). Firefighters would not be allowed to work under the influence of alcohol; however, they are required to work under the influence of fatigue on a daily basis.

Statement of Purpose

Employers have a duty to protect their employees from recognized hazards. This duty has not been fully met by leaders within the fire service. Firefighting is continually ranked among the most dangerous and stressful jobs in the US (Suneson, 2019). The risks of sleep deprivation and fatigue have been recognized for decades. The International Association of Fire Chiefs has published a report on the topic (2007) and recommended action be taken to combat this serious safety and health issue. Furthermore, it is a frequent topic in industry published work such as Firehouse and Fire Engineering. Despite being a recognized hazard and receiving much attention, little to no action has been taken to combat the issue. Firefighters are being injured at a rate four time higher than all other occupations combined (Bureau of Labor Statistics, 2013). They are exhibiting undeniable symptoms, at rates far exceeding the general population. Much of the risk firefighters are exposed to during the course of their job duties cannot be controlled or eliminated. The injuries, illnesses, and fatalities caused by fatigue and sleep deprivation are preventable. These risks can be quantified and managed. Research is needed to identify when impairment begins, recovery time needed, and appropriate measures to address the fatigue problem. The purpose of this study is to understand the relationship between sleep quantity, quality, workload, and cognitive function in firefighters working 24 and 48-hour shifts.

CHAPTER II

REVIEW OF LITERATURE

Firefighter Cognitive Fatigue Research

It is evident that fatigue is a contributing factor to injuries experienced by firefighters. Since 45% of these injuries are related to overexertion and bodily reactions, it is important to understand how fatigue develops across the course of a shift and how recovery takes place. Despite the astonishingly high injury rates, however, research on firefighter fatigue is surprisingly sparse. A review of literature including the key terms "fatigue" and "firefighter(s)" returned only 248 peer reviewed articles in English, the vast majority of which were related to the physical demands of the job. Fatigue, however, is a complex concept that may manifest from physical or cognitive strain, or a combination of both. Adding the modifier "cognitive" to the literature search reduced the number of articles to 52. A review of the abstracts for all 52 articles further reduced the relevant research on evaluation of cognitive fatigue in firefighters to six articles, half of which also addressed recovery.

Of the studies conducted with firefighters, two were conducted in the field. Paley and Tepas (1994), evaluated firefighters' fatigue, for 20 firefighters during their shifts. However, this study involved firefighters who were on eight-hour rotating shifts, a shift schedule which is not common in the U.S. The purpose of this study was to track time-of-day and time-on-task differences in mood and fatigue. It collected information on the average quantity of sleep firefighters received per night and subjective feelings of sleepiness and mood throughout the shift. They found the night shift receives the least amount of sleep, followed by morning shift, and the afternoon/evening shift received the highest amount of sleep (Paley & Tepas, 1994). They found no significant difference in mood and fatigue throughout the week, however, they did find a significant difference in mood and fatigue related to both time-of-day and time-on-shift (Paley & Tepas, 1994). Moods were lower and fatigue higher at the end of each shift regardless of time-of day. Furthermore, moods were lower and fatigue was higher for those on the night and morning shifts compared to the afternoon/evening shift.

This study focused on mood and did not assess other relevant cognitive factors such as reaction time or error rate. An additional weakness of this study is that they did not track the actual quantity or quality of sleep that firefighters received day to day, instead they had firefighters estimate the number of hours they usually sleep each night, prior to the collection of mood and fatigue data. The results found in this study are in line with results found in similar studies conducted in other professions.

Takeyama et al. (2005), also evaluated cognitive abilities throughout firefighters' entire shift. These firefighters, however, slept in separate rooms and each firefighter was only woken during one of five, two-hour periods in which they were required to respond to calls during the night. They found that the firefighters who were responsible to respond between 0130 and 0330, as well as those responsible to respond between 0315 and 0515, took shorter naps and had higher rates of subjective complaints of fatigue. Heart rate variability was significantly lower for those responding between 0315 and 0515, than for those responding between 0500 and 0700. These results indicate a time-of-day effect, consistent with night shift studies in other professions working shifts.

The Takeyama et al. (2005) study included several limitations to generalizability. The condition under which these results were found is unrepresentative for the vast majority of fire stations in the U.S. Most fire stations provide dormitory type sleeping accommodations, where everyone is awakened by alarms, throughout the night, regardless of whether they are required to respond or not. Though this study revealed time-of-day influences on cognitive function of firefighters, it did not indicate at what point cognitive performance began to be impaired; nor did they evaluate the time required to recover from cognitive impairment within, or following the shift. Additionally, the cognitive performance data that was collected was subjective and had more to do with feeling and mood than actual ability to effectively complete tasks.

One study, Armstrong, et al. (2013), took place under simulated working conditions at a wildfire training facility. In this study, 25 volunteer firefighter participated in a four-day study in which they performed simulated wildfire work activities on a rotating basis. Participants were provided an 8-hour, uninterrupted sleep opportunity at the training facility. Day one the participants had breakfast, were briefed on activities and baseline testing was conducted. Following lunch, the participants began rotating through cycles of 55 minutes of physical work, 20 minutes of physiological testing, and 20 minutes of cognitive testing. They completed three cycles each afternoon and two cycles each morning. Following their evening meal, they were allowed 6 hours of free time, followed by a four-hour sleep opportunity. On day three they were allowed two hours of free time and eight hours of sleep opportunity. Participants were asked to provide subjective analysis of their own performance prior to and following objective performance testing (measured by reciprocal reaction time on PVT).

This study concluded that cognitive performance continually declined as sleep debt accumulated, but returned to baseline following eight hours of uninterrupted sleep. Furthermore, the participants were not able to accurately assesses their own performance abilities pretest (they didn't think they were as heavily impacted as they actually were), however, they were able to more accurately assess their own performance after the cognitive assessment (they realized they were doing worse than anticipated). Although self-assessments post-test showed increased awareness of performance decrement, neither assessment was found to be a significant predictor of actual performance (Armstrong, Cvirn, Ferguson, Christoforou, & Smith, 2013).

Though the physical workload in this study is more representative of what firefighters may face on the job than laboratory studies, wildland firefighting is much different than municipal firefighting. Additionally, the simulated tasks were all manual labor (raking, rolling hose, etc.) and did not take into consideration the stress involved in responding to calls, dealing with people, medical treatment and other aspects that may be more cognitively taxing than purely physical tasks. The participants of the study were also provided six hours of personal time, where they could physically rest (day 1 and 2), and four hours of uninterrupted sleep time each night (day 1 and 2), which does not represent “real-world” working conditions for firefighters, in which they may be called upon to respond at any time of the day or night.

The other three studies specific to firefighters, were conducted in laboratory settings with simulated workloads for 18 minutes (Greenlee et al., 2014), 50 minutes (Morley et al., 2012), and 24 hours (Kujawski et al., 2018). Greenlee et al. (2014) and Morley et al. (2012) both addressed recovery time. Both studies found that cognition was not immediately affected. Morley et al. (2012) did, however, find delayed cognitive impartment after a short period of rest, for firefighters who were subjected to 50 minutes of intense physical activity, in a heated room, while wearing full gear. Full cognitive recovery from short-term, simulated, physical activity occurred within 120 minutes after stopping the activity. These simulated tasks provide some insight to the development and recovery of cognitive fatigue; however, they are not representative of the combined physiological and psychological strain that a firefighter may be exposed to repeatedly during the course of their shift; nor are they representative of the impact of a full 24-hour shift. Additional research is needed to determine if this delayed cognitive impairment is compounded by repeated responses that do not allow for the firefighter to rest until full cognitive recovery is obtained.

The only laboratory study that evaluated firefighters for a full 24-hour time frame, Kujawski et al. (2018), is the most relevant of the laboratory studies because it evaluated the entire time frame that the firefighters would normally be on duty, while also subjecting them to physical activity and non-subjective cognitive testing (tested for actual performance decrement). The participants’ cognitive functions were evaluated at the beginning, middle, and end of the 24-hour period. The second and third tests showed significant decrease in accuracy of responses. Some test showed improved reaction time, but increased number of incorrect responses. Like the other two laboratory studies, this form of testing is not representative of actual workplace stressors, which is a common limitation to laboratory and simulated task studies (Williamson et al., 2011). Test subjects were required to stay awake for the entire 24-hour period, their activities were monitored, but not directed between bouts of physical activity, and subjects were required to refrain from use of alcohol and caffeine or other stimulants for 12 hours prior to testing (Kujawski et al., 2018). These restrictions were meant to limit the influences on the outcome of the test; however, they could result in outcomes significantly different from those obtained under normal workplace conditions.

Research is needed to evaluate the development of fatigue across the course of an entire shift, within the work environment, under normal working conditions to determine the impact fatigue has on firefighters' ability to perform work safely, effectively, and efficiently. Although fatigue is recognized as a problem within the fire service (Czeisler et al., 2019; Elliot & Keuhl, 2007; Peterson, 2016) the impact fatigue exerts on performance has not been quantified in the field in a context that is generalizable to the majority of fire departments within the U.S. This information would allow for identification of periods when the firefighter is at increased risk of making poor decisions or mistakes that could result in injury to themselves or those around them, failure to respond quickly enough, or other performance related deficiencies that could result in a negative outcome. Additionally, research needs to evaluate recovery time needed for cognitive performance to return to baseline during and following the completion of a shift. This may justify the need for additional staffing or a change in shift structure which would relieve some of the pressure to work overtime.

Defining Fatigue, Sleepiness, and Recovery

Literature that directly evaluates cognitive fatigue among firefighters is severely lacking. Studies on this topic have been conducted quite extensively in a variety of other fields, for more than a century (Noy et al., 2011). Some fields in which the research is extensive include nursing, medical residency, military, transportation, aviation, and industrial settings. Though the findings from this research are not directly generalizable to firefighters, it has laid the foundation for defining and measuring fatigue over shorter durations. Research pertaining to firefighter fatigue may therefore, expand upon this previous research.

Defining Fatigue

There is no concise, nor universally accepted, definition for fatigue (Cavuoto & Megahed, 2017; Noy et al., 2011; Wadsworth, Allen, Wellens, McNamara, & Smith, 2006). George Poore introduced a framework for fatigue, in which he distinguished between acute and chronic fatigue in 1875 (Rabinbach, 1992). Acute fatigue is "mental fatigue due to mental overload or underload, or physical fatigue" (Brake & Bates, 2001, p. 456). In contrast, chronic (long-term) fatigue, often associated with illness, as well as mental and physical disorders; is fatigue that has accumulated to the point that it no longer responds to efforts to compensate (MacLaren, Gibson, Parry-Billings, & Edwards, 1989; Wadsworth, Winefield, Dawson, & Lushington, 2005). Other researchers have described fatigue as, "a physical and moral disorder that results in a disruption of function, a breakdown of body and mind, an impairment of the will, and complete exhaustion" (Noy et al., 2011, p. 496). Wadsworth et al. define it as "a subjective sensation with behavioral, emotional, and cognitive components" (2006, p. 836). Strauss, offered what is probably the most concise definition, "a non-pathological state resulting in a decreased ability to maintain function or workload due to mental or physical stress" (2003, p. 1). Kant et al. (2003), added that it is best described as a continuum, rather than a state of being. With decades of research, the definition seems to be getting more complex, rather than being refined.

Some of the difficulty in defining fatigue may be related to efforts to differentiate between physical and cognitive fatigue. Neither are clearly defined by research and often there is no attempt to distinguish between the two concepts even when the study is only measuring for one or the other. From the review of literature, it seems evident that physical fatigue is the reduced function of the musculoskeletal system due to environmental factors such as physical force required to complete the task, heat, rate of work performance, repetition of motion, time on task, etc. The effects are exacerbated by reduced sleep quantity and/or quality. Symptoms of physical fatigue may also include cognitive impairment, however, studies have shown this impairment, when solely caused by physical fatigue, is short-lived and improves with rest following the physical activity (Morley et al., 2012).

Similarly, cognitive fatigue is the reduced function of the nervous system due to environmental factors that cause stress or anxiety, such as solving a difficult problem, maintaining attention for long spans of time, multiple signals being received at the same time (many people talking, lights, sounds) etc. This type of fatigue diminishes cognitive functions such as the "ability to think clearly, slows reaction time, and decreases attention, vigilance, short-term memory, judgement and other functions" (Cian, Barraud, Melin, & Raphel, 2001; Gopinathan, Pichan, & Sharma, 1988; National Safety Council 2019c, p. 5). Cognitive fatigue is also intensified by reduced sleep quantity and/or quality and may also be amplified by physical fatigue.

The concepts of physical and mental fatigue are so closely related that some studies have concluded that the two must be evaluated in tandem (Ahmed, 2019; LaManca et al., 1998; Liu et al., 2003). A variety of models have been developed to predict fatigue in different situations (health conditions, workload, etc.). However, researchers have found that there is interaction between physical and mental fatigue and the direction of that relationship has not yet been established. Models developed to predict total fatigue, have produced more reliable results than those which have attempted to separate the two concepts (S. Ahmed, 2013).

Defining Sleepiness

Some of the confusion surrounding fatigue research may also be created when the terms sleepy and fatigue are used interchangeably in the literature. The terms sleepiness and fatigue are two mechanisms that work synergistically, however, they are not synonymous (Thomas J. Balkin & Wesensten, 2011). Sleepy, as defined by Merriam-Webster Dictionary (2020), means "ready to fall asleep." Whereas, fatigue means "weariness or exhaustion from labor, exertion, or stress" (Merriam-Webster Dictionary, 2020). According to these definitions, sleepiness implies a lack of sleep as causation, while fatigue implies physical and/or mental stress as causation. This research will use the terms sleepy and fatigue as defined by Merriam-Webster Dictionary.

The literature points to circadian rhythms, insufficient sleep and/or poor-quality sleep as factors that cause sleepiness (Billings & Focht, 2016; Cheng, Tallent, Bender, Tran, & Drake, 2017; Dawson, Ian Noy, Härmä, Kerstedt, & Belenky, 2011; Paterson, Aisbett, & Ferguson, 2016; Rudin-Brown et al., 2019; Strauss, 2003; Williamson et al., 2011). The circadian rhythm is the body's normal 24 hour cycle of sleep and wakefulness (Dinges & Kribbs, 1991). Requiring the body to be awake when it would routinely be asleep causes disruption to the sleep cycle and increases feelings of sleepiness. As little as 2-3 hours' sleep interruption in a single night can impact performance (Dawson et al., 2011). Additionally, because the body conducts restorative functions during the sleep cycles, being awake when the body is normally asleep impedes the bodies repair functions. These leads to reduced physical and mental capacity.

During sleep, the body goes through four stages of progressively deeper sleep, with each stage lasting approximately 90-120 minutes (Adler, 2020). Typically, the body cycles through each of these stages several times each night. When a sleep stage is interrupted the body does not return immediately to that stage, but must start over at stage one and begin working through the cycle again. If sleep is repeatedly interrupted, the deep sleep stage may not be reached. Interruptions of the sleep cycle result in poor-quality rest, which inhibits the body's ability to completely restore physical and mental resources (Billings & Focht, 2016). Likewise, insufficient sleep (less than 7-9 hours per night) may not allow enough time for the body to experience repeated full cycles of sleep. This will also lead to insufficient recovery and feelings of sleepiness. Chronic exposure to sleep deprivation (reduction of sleep over multiple nights) can lead to accumulated sleep debt and impairment that is equivalent to or greater than that which is produced from acute sleep deprivation (Dawson et al., 2011).

Defining Recovery

Recovery, as defined by Akerstedt et al. (2000), is “feeling alert and fresh during the day” (p. 252). No additional clarification is offered to explain what constitutes “alert” or “fresh.” Totterdell et al. (1995), define it as “the period of time that an individual requires to return to a normal or pre-stressor level of functioning following the termination of a stressor (p. 44).” Craig and Cooper (1992), agree with Totterdell et al. on this definition for psychological recovery. This is the definition of recovery that will be used for this study.

The body goes through a cycle of peak performance, diminishing performance, and restoration (Williamson et al., 2011). This performance cycle will expand and contract based on many work and recovery related factors. As long as the need for restoration (recovery) is unsatisfied, performance will be impaired. Rosa & Colligan (1988) verified that two days were sufficient time for cognitive recovery for data entry workers working five, twelve-hour shifts. However, Totterdell et al. (1995) found that three or more days may be necessary for shift working nurses. Akerstedt et al. (2000) conducted research in a variety of irregular work schedules. It is important to note that they define a recovery day as the first full day after a full night of sleep. Their results indicated: 8-hour days/ 40-hour weeks required one day for recovery, irregular night/morning shifts on four to five day work-weeks required one day for recovery, traditional three shift work (eight hours per day, weekly rotation through each shift) one day was required for recovery, extremely rapid-rotating three-shift work required one day for recovery, seven consecutive 12-hour days required three to four days for recovery, and 14 consecutive 12-hour night shifts required six days for recovery. Wadsworth et al. (2006) found that seafarers, whose tours of duty were between 28-35 days, needed a full week to recover. No studies were found to indicate recovery time needed for firefighters on a 24 or 48-hour shift.

Measuring Fatigue, Sleepiness, and Recovery

Cognitive fatigue has been connected to poor decision-making (Cavuoto & Megahed, 2017), decreased attention, increased reaction time (Gerdes, Kahol, Smith, Leyba, & Ferrara, 2008; Lombardi, Folkard, Willetts, & Smith, 2010; Morley et al., 2012; Scott, Rogers, Hwang, & Zhang, 2006; Williamson et al., 2011), incorrect reaction (Williamson et al., 2011), and other cognitive impairments that increase the risk of accidents and injuries (Gerdes et al., 2008; Morley et al., 2012; Mountain, Quon, Dodek, Sharpe, & Ayas, 2007; Scott et al., 2006; Smith, Folkard, Tucker, & Macdonald, 1998). For firefighters, this may result in increased injuries or death for themselves or their coworkers, equipment damage, or catastrophic results for patients they are treating during emergency response or rescue operations (Morley et al., 2012). Since local governments spend an estimated $68 million annually for injuries (not including equipment damage or litigation), identifying the factors that increase this risk, as well as developing proactive interventions can be useful in reducing the cost (Lexipol, 2018).

Measuring Fatigue

There is no standard method for measuring fatigue (Cavuoto & Megahed, 2017). Fatigue is a complex, multifaceted concept that is difficult to define and measure, because it cannot be directly observed (Williamson et al., 2011). It is not a state of being, but rather a continuum. Further confusion is created when the term fatigue is used to refer to observed symptoms, rather than the cause of the symptoms. The result of fatigue cannot be fatigue; it must be some other observable and measurable factor. Research has made progress in identifying symptoms of fatigue, which can be both observed and measured. The symptoms arise from internal and/or external stressors which exceed the body's resources for compensation (Aaronson et al., 1999). Carpenito (1995) states that symptoms of fatigue, including exhaustion and decreased mental or physical capacity, are sustained and are not relieved by short rest breaks. Though exhaustion may be difficult to quantify, the symptoms of mental or physical capacity can be measured via physical and/or mental assessments. Therefore, these are the measures typically used to diagnose or evaluate the presence of fatigue.

Methods that have been identified in previous research as effective measures of fatigue include heart rate monitoring (Cavuoto & Megahed, 2017; Yung et al., 2014), heart rate variability (Burch et al., 2019; Rodrigues et al., 2018; Takeyama et al., 2005), body temperature (Morley et al., 2012), pupil dilation (Cavuoto & Megahed, 2017; Kahneman, 2015), self-reported symptoms surveys (when combined with other verification methods) (Cavuoto & Megahed, 2017; Powell & Copping, 2016; Yung et al., 2014), and psychomotor vigilance tasks (PVT) (Cavuoto & Megahed, 2017; Morley et al., 2012; Powell & Copping, 2016). Equipment necessary for monitoring pupil dilation and heart rate variability make these methos more practical for laboratory settings than field studies. Equipment necessary to conduct the remaining methods are readily available within fire departments and are therefore practical methods for this study.

Although previous research has commonly used self-reported symptoms of fatigue as a method of data, some research has shown that people are typically poor at recognizing their own fatigue (Horne & Baulk, 2004; Kaplan, Itoi, & Dement, 2007; Lockley et al., 2007; Scott et al., 2007), until they begin nodding-off (National Safety Council, 2019b). Cognitive performance, however, is impaired before that point (Powell & Copping, 2016). One of the strongest indicators that fatigue is present is diminished worker performance. Either physical or cognitive impairment, individually or a combination of the two, may result in reduced performance (Cavuoto & Megahed, 2017; Sedighi Maman, Alamdar Yazdi, Cavuoto, & Megahed, 2017). Additionally, fatigue may be exacerbated by psychological, physiological, socioeconomic, and environmental factors (Sedighi Maman et al., 2017; Yung, Bigelow, Hastings, & Wells, 2014). Furthermore, tolerance for fatigue varies by individual and exposure. What is easily tolerated by one worker may be completely intolerable to another, or what is easily tolerated by a worker one day, may be more difficult to tolerate on a different day, by the same worker.

The PVT is one of the most frequently used measures of cognitive performance (Thomas J. Balkin & Wesensten, 2011)(Thomann, Baumann, Landolt, & Werth, 2014). Several researchers have reported Psychomotor Vigilance Test (PVT), especially reaction time, is sensitive to sleep loss and fatigue (Balkin, Horrey, Graeber, Czeisler, & Dinges, 2011; Dinges et al., 1997; Dorrian, Rogrers, & Dinges, 2005; Stout, Beidel, Brush, &

Bowers, 2020; Williamson et al., 2011). This test collects data on response time, which is an indicator of how quickly a test subject is processing signals. Response time is reported in milliseconds. Response times between 150 to 500 milliseconds are considered alert responses. Whereas, responses beyond 500 milliseconds indicate impaired performance (Ackerman, 2011; Thomas J. Balkin & Wesensten, 2011; Thomann et al., 2014). Past studies have shown that reaction time is more often affected than accuracy on simple tasks (Dinges & Kribbs, 1991; Stenuit & Kerkhofs, 2008).

Accuracy is indicated by the number of errors occurring during the test. Errors are categorized as either lapses or false starts. Lapses are recorded as the total number of responses with latency greater than 500 milliseconds. False starts are recorded as the total number of times responses occur, during a test block, in the absence of stimuli. Both types of errors are typically combined into one variable – total errors (# of Lapses + # of False Starts). Though some studies only evaluated response time, one study indicated that reaction time and number of errors may be affected differently by fatigue. Morley et al. (2012) found that following intense physical activity, firefighters' response times decreased, while the number of errors increased.

Factors that have been found to be relevant influencers of fatigue development include workload (Morley et al., 2012), time since waking (Williamson et al., 2011), start time (Billings & Focht, 2016; Harrington, 2001), time of day (Folkard, 1997; Williamson et al., 2011), time on task (Bendak & Rashid, 2020; Cavuoto & Megahed, 2017; Harrington, 2001), and quantity and quality of sleep (Billings & Focht, 2016). Some studies only collect one, or a few, of these factors and do not account for the others. Failure to account for all variables is more likely to produce confounding results. Best practices for studying the effects of these variables requires collecting all and controlling for the effects of each during evaluation (Williamson et al., 2011).

Workload. Morley et al. (2012) found that detriments to cognitive abilities were not apparent immediately following physical exertion, however within one hour of intense physical performance (heart rate approaching maximum), recall and psychomotor vigilance were significantly impaired, despite having rested. Grego et al. (2005), found similar results, in their study, performance was enhanced immediately following physical exertion, but reaction errors were significantly higher after a two-hour rest period. This was also the result in Fan and Smiths (2017) study which found that as fatigue increased, response time decreased, while error rates increased. For firefighters, this could mean they perform well on an initial call, but have negative consequences for subsequent responses.

Workload can be measured objectively or subjectively. Subjective measurements involve the participant feelings about the effort required to perform the work. Objective measures on the other hand use biometric information to determine how hard the body is working. Subjective measures have been found to be sufficient measures to explain performance detriments, but objective measures provide a more reliable measure (Fan & Smith, 2017).

Heart rate is sensitive to both physical and mental demand and is commonly used to evaluate effort required to accomplish a task. Effort can be measured by energy exertion. The most objective form of measuring energy exertion requires the use of calorimetry (Garet et al., 2005). This is the “process of measuring the amount of heat released or absorbed during a chemical reaction (LibreTexts, 2019)." In reference to human performance, it involves measuring energy expenditure by calculating the body's use of oxygen and creation of carbon monoxide. Several methods have been proposed for estimating energy expenditure using alternative methods, that do not require a laboratory setting. Garet et al (2005) evaluated some of those methods and found the Corrected Heart Rate Estimated Energy Expenditure model (CHREEE) is able to accurately estimate energy expenditure using the following equation:

$$CHREEE= [HR – HR_{rest} + 15) / (HR_{max} – HR_{rest} +15)]100$$

Where HR is heart rate, HR_{rest} is resting heart rate, and HR_{max} is maximum heart rate. Maximum heart rate is determined by subtracting the subject's age from 220, for example a maximum heart rate for a 20 year old person is 200 (American Heart Association, 2015).

Time Since Waking. When a person first awakens, they are in a state called "sleep inertia" (Mountain et al., 2007). Cognitive function is at its lowest during the first 10-15 minutes after awakening, but the effects of sleep inertia may last up to several hours (Jewett et al., 1999; S. W. Lockley et al., 2007). In their research, Wertz, et al. (2006), found that sleep inertia has a more profound effect on cognitive ability than 26 hours of total sleep deprivation. Additionally, they found that effects of sleep inertia increases in combination with sleep deprivation and at low points within the circadian rhythm (Wertz et al., 2006). It can be interpreted from this information, that those who are sleep deprived, and must be awaken at night for work (such as firefighters and emergency responders), may be suffering from high levels of cognitive impairment while attempting to complete tasks.

Start Time. Traditional start time for industrial morning shifts is 0600, which interferes with the completion of the circadian rhythm's final cycle of REM sleep (Harrington, 2001). Some research indicates that the most effective sleep cycle occurs around 0600 (T. Akerstedt & Folkard, 1995; Folkard, 1997; Williamson et al., 2011; Zulley, 1990). The average start time for firefighters is 0700, with earlier or later times in some regions. Depending on local traffic schedules and travel distance, arriving at work by 0700 may require one to rise and prepare for work around 0500; earlier for those who have a long commute. This may mean that on the day that a firefighter reports for duty, his or her sleep cycle will be interrupted, increasing the level of fatigue that is experienced from the beginning of the shift.

Time of Day. Those who work night time or extended shifts must work against the body's natural circadian rhythm. Even without sleep deprivation, cognitive performance has been shown to be affected by the body's circadian rhythm (Mountain et al., 2007). According to the NSC, the average person is most alert around 1000 (2019a). This alertness diminishes across the course of the day. Around 2100 melatonin begins to secrete causing the sleepiness to occur (National Safety Council, 2019a). Deepest sleep, for the average person, occurs around 0200 when melatonin levels are the highest (National Safety Council, 2019a). Around 0700 the body stops secreting melatonin and wakefulness begins to increase until it reaches its peak again around 1000.

Hypothetically, based on this circadian rhythm, incidents due to fatigue should be highest during the time period when the body is fighting against the melatonin in its system, between 2100 and 0700. Research on the peak times for incidents has been varied and does not consistently support this hypothesis. Harrington (2001), states that a variety of studies have indicated 1000, 1100, 1300, and 1600 are peak times for injuries, though he did not cite the sources for these studies. Folkard (1997), found peak times for traffic incidents to be between 0200 and 0300, 1400, and 2100. Additional studies conducted in industrial settings, had remarkable similar findings with peak risk for incidents occurring at or near midnight (Fathallah & Brogmus, 1999; Folkard, Lombardi, & Spencer, 2006; Fortson, 2004). The variability of the findings on peak accident times, as well as case studies of some of the most catastrophic human-made disasters of our time, indicate that these "peak times" are not generalizable outside of the field in which the study was conducted (Williamson et al., 2011).

Time on Task. It is interesting to note that in several of the catastrophic events, such as Three-mile Island, Chernobyl, Exxon Valdez, and the Challenger Space Shuttle Explosion, occurred at times when employees had been at work for an extended period of time (Harrington, 2001). This could indicate that time on task is a more influential variable than time of day. Folkard and Lombardi (2006) found that the risk of injury begins to increase after eight hours of work, this amplification of risk increases by 13% after 10 hours on the job, and increases by 30% after 12 hours on the job. Dawson and Reid (1997), found that a person may be so fatigued after 16 hours that he/she may no longer be capable of performing at the desired level. In a comparison of eight hour and twelve hour shifts, Mitchell and Williamson (2000), found no difference in performance or fatigue, however employees on the twelve hour roster had higher error rates during the last four hours of their shifts. Similar results were found in the medical field, with nurses' error rates increasing three times higher for those working 12.5-13 consecutive hours (Lockley et al., 2007). With medical residents working 24 to 30 hour shifts, alertness and performance dropped dramatically after 16 to 18 hours on the job (Lockley et al., 2007).

Research indicates decreased cognitive function observed in "time on task" studies may be related to lack of arousal (decreased attention) rather than fatigue (Manly, Robertson, Galloway, & Hawkins, 1999; Pattyn, Neyt, Hendrick, & Soetens, 2008). Smith (1998), found no difference in error rates or attention in industrial workers working eight- or twelve-hour shifts. Manly et al. (1999) found that decreased attention and increased missed signals were only apparent with simple (potentially boring) tasks. Proponents of resource theory, explains that simple tasks may result in higher detriment, because vigilance is diverted to more complex tasks, rather than resulting from lack of arousal (Helton & Warm, 2008; Smit et al., 2004). Recent research suggests performance may be improved through increasing arousal (Gershon, Ronen, Oron-Gilad, & Shinar, 2008; Oron-Gilad, Ronen, & Shinar, 2008). Further research is needed to resolve the mechanism of detriment that has been observed in work extending beyond 10 hours (Williamson et al., 2011).

Quantity/Quality of Sleep. The quantity and quality of sleep has consistently been found to effect cognitive ability and increase the risk of injury and error (Conner et al., 2002; Cummings, Koepsell, Moffat, & Rivara, 2001;Hursh et al., 2004; Landrigan et al., 2004; Lockley et al., 2004; Patterson, Suffoletto, Kupas, Weaver, & Hostler, 2010).

Wadsworth et al. (2006) found that reducing total sleep time by as little as 1.3-1.5 hours for one night can reduce daytime alertness by as much as 32%. In a study of medical interns, studies found 21% increase in medication errors, 36% increase in serious medical errors, and a six-fold increase in serious diagnostic errors among interns who worked on-call for 24 hours, as opposed to those who were continuously on shift for 16 hours (Landrigan et al., 2004; Lockley et al., 2004). Additionally, Lockley et al. (2007) found that physicians-in-training who worked 24-hour shifts were 300% more likely to make errors that would result in patients' death. It is evident that working for long periods of time without sleep can have a significant impact on error rates.

In addition to increasing error rates, lack of sleep can increase reaction time and increase risk. In a study of traffic accidents, Cummings and colleauges found the risk of automobile accident is lowest when subjects had 15 hours of sleep within the past 48 hours (2001). This study found that the risk of crashing is positively correlated with the number of hours slept with the past 48 hours. Their results indicate risk for those who only had 12 hours of sleep was significantly higher than the risk for those who had between 15 and 21 hours of sleep within the past 48 hours. Furthermore, the risk doubles for those who have had nine or less hours of sleep. In another study, Conner et al. (2002) identified five hours of sleep within 24 hours as the threshold for increased risk. No study was found that indicates a threshold for diminished cognitive function and increased risk among firefighters.

Research has consistently shown that firefighters are sleep deprived and the quality of their sleep is reduced by frequent interruptions both on and off shift (Billings & Focht, 2016; Carey, Al-Zaiti, Dean, Sessanna, & Finnell, 2011; Lusa, Hakkanen, Luukkonen, & Viikari-Juntura, 2002; Mehrdad, Haghighi, & Esfahani, 2013; Patterson et al., 2010). Waking several times during the night is normal, but one gains little value from sleep if he or she is awakened frequently (Powell & Copping, 2016). Billings and Focht (2016) found that firefighters experience poor sleep quality due to frequent sleep interruptions while on shift. Surprisingly, they did not find a significant difference between the sleep quality of firefighters on 24-hour shifts and those on 48-hour shifts. Conversely, they did find that sleep quality is diminished by having a second job. They surmise this is due to the inability to sleep at the second job, which interferes with the body's ability to recover from sleep loss.

Knauth (1996) claims that sleep loss following one night time shift can be compensated with ample sleep the following day. Sleep loss from working consecutive schedules after one week, however, may no longer be compensable. Work schedules that result in losing an hour or two each day may lead to an accrued sleep deficit. Accrued sleep deficit results in physical or psychological impairment. Furthermore, accrued sleep deficit may have detrimental effects for both the firefighter and his/her employer, as this increases the probability of diminished performance, error rates, and incidents by reducing attention and increasing reaction time.

Most methods of identifying symptoms of fatigue (both physical and cognitive) have been reactionary; they identify symptoms after fatigue is present or quantify the impact of the symptoms. To reduce risk and decrease performance impairment, researchers have developed a variety of models aimed at predicting the presence of fatigue. Van Dongen (2004) provided a comparison of models for a variety of data sets. He concluded that all of the models had difficulty accurately predicting subjective data (reported feelings of sleepiness). However, this difficulty could be related to the subjectivity of the ratings; different people may rate the same level of fatigue differently. Additionally all of the models were able to predict acute performance impairment, but had difficulty doing so across longer time spans and tended to overestimate performance detriment (Van Dongen, 2004).

Later evaluation of bio-mathematical models for fatigue indicated that they have progressed to a variety of two-process models and three-process models (Dawson et al., 2011). Two-process models take into account sleep and predict alertness, but do not take into account workload. In other words, they are predicting sleepiness, not fatigue as defined earlier in the literature review. Three-process models build on the two-process models and account for sleep inertia. These models take into account not just sleep/wake cycles, but also work/rest cycles (Dawson et al., 2011). The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model is one of the most advanced three-process models with inputs for sleep-wake history (measured directly by actigraph), shift scheduling (Dawson et al., 2011). It was first developed for use with the Department of Defense (Powell & Copping, 2016). It has since been updated and validated multiple times in laboratory and field studies (Devine, J.K., Chinoy, E.D., Markwald, R.R., Schwartz, L.P., Hursh, S.R., 2020; Devine et al., 2021; Hursh et al., 2004; Roma, Hursh, Mead, & Nesthus, 2012). It has been found to be an effective, predictive model for human performance (Powell & Copping, 2016) and is now the model used by the US Department of Defense, the US Department of Transportation, and the Federal Railroad Administration to schedule operators (Institutes for Behavior Resources, 2016).

Measuring Sleepiness

Subjective. A variety of subjective measures for measuring sleepiness have been used for decades. Some of the more frequently used scales include visual analogue scales (VAS), the Epworth sleepiness scale (ESS), the Stanford sleepiness scale (SSS), and the Karolinska sleepiness scale (KSS) (Drake, 2011). The visual analogue scale is a simple tool which usually only consist of one question that asks how likely the participant is to fall asleep, followed by a line where one end indicates the participant would not fall asleep and the other end the line indicates the participant would definitely fall asleep. The participant responds by marking a location on a line to indicate how likely they are to fall asleep (Lu, Sesek, Megahed, & Cavuoto, 2017). A drawback of the VAS is that many studies do not establish reliability or validity of the measure (Tseng, Gajewski, & Kluding, 2010).

The Epworth sleepiness scale (ESS) is used to examine daytime sleepiness across the course of an entire day (Shahid, Wilkinson, Marcu, & Shapiro, 2011). It asks participants to rate, on a scale of 0-3, the likelihood of falling asleep during eight different activities; ratings are then total to achieve a score between 0-24 (Shahid et al., 2011). Dr. Murray Johns, the developer of the ESS suggests scores higher than 10 potentially indicate daytime sleepiness at a clinical (M. W. Johns, 1991). This scale has been used in both research and clinical settings (M. W. Johns, 1991; M. Johns & Hocking, 1997; M. W. Johns, 2000). This scale is copywritten and cannot be used or reproduced without permission (Shahid et al., 2011).

The Stanford Sleepiness Scale (SSS), like the VAS also consists of only one item. The SSS, however, requires participant to respond on a Likert scale, by choosing one of seven responses that most accurately represents their perceived level of sleepiness. This test is simple to administer, has been validated, has been found to be useful in predicting performance in alertness tasks and rating sleepiness at repeated times through the study timeframe (Drake, 2011; Lu et al., 2017; Shahid, Wilkinson, Marcu, & Shapiro, 2011). One study found this scale to be useful for predicting performance in sleep deprived participants, but less effective for predicting performance in partial sleep deprived or well rested participants (Broughton, 1982). One limitation to using this scale is that it may cause confusion between sleepiness and other forms of fatigue. The phrases used in the scale rate sleepiness using terminology such as “active” and “responsive” on the lower end of the scale but only use sleep related terns such as “fighting sleep” and “sleep onset soon” at the higher end (Shahid et al., 2011).

The Karolinska sleepiness scale (KSS), like the SSS requires participants to respond to a Likert scale, but is a nine-point scale. It uses similar terminology to the SSS, but leaves out references to activity and focuses only on sleepiness (Shahid et al., 2011). Also, like the SSS, the KSS uses only one question, is useful for measuring sleepiness at repeated times per day, and is easily administered in the field. The KSS, however, has been validated against EEG and found to be highly correlated (Shahid et al., 2011). A limitation is that it may be affected by time of day/circadian rhythms (Akerstedt, Hallvig, & Kecklund, 2017; Shahid et al., 2011). Despite this potential limitation, the scale has been used in a variety of laboratory and field studies because of its strong correlation to electroencephalography (EEG) results (Åkerstedt et al., 2000; Armstrong et al., 2013;

Bendak & Rashid, 2020; Elliot & Keuhl, 2007; Howard et al., 2007; Knauth, 1996; Van Dongen, 2004; Williamson et al., 2011).

Objective. In past research sleep journaling has been a frequently used measure to document the amount of sleep obtained. However, this method relies on participants to accurately document their sleep. In more recent research wearable sensors are becoming a low cost, readily available, and reliable method for tracking quantity and quality of sleep in addition to other biometric variables (Sedighi Maman et al., 2017). Just as the emphasis in research has been on physical fatigue, so too has the development of wearable sensors. They are predominately used to detect physical fatigue in athletics, sleepiness in miners, and drowsiness in the transportation industry (Sedighi Maman et al., 2017). EEG is the most commonly used sensing device for collecting data on sleep patterns. The actigraph is the second most commonly used device and is more prevalent is situations where researchers seek to observe both the sleep and wake patterns (Imtiaz, 2021) Actigraphs typically only do not provide data on the stages of sleep (Imtiaz, 2021). The Zulu watch, however, does collect this information and has been evaluated against polysomnography (PSG) and actigraphy for performance in sleep-wake determination in the laboratory and evaluated against self-report in the field (Devine, J.K., Chinoy, E.D., Markwald, R.R., Schwartz, L.P., Hursh, S.R., 2020).

Measuring Recovery

Recovery is the amount of time needed for cognitive functions to return to baseline, or pre-stressor levels (Jansen, Kant, Van Amelsvoort, Nijhuis, & Van Den Brandt, 2003). Research indicates the need for recovery is driven by work intensity and time on task (Beurskens et al., 2000; Jansen et al., 2003; Lu, Sesek, Megahed, & Cavuoto, 2017; Sluiter, Van der Beck, & Frings-Dresen, 1999). Work schedules are therefore, important factors in the ability of workers to fully recover from work (Jansen et al., 2003). Firefighters' cognitive functions need to be evaluated throughout an entire shift (or tour if working more than 24 hours), to determine at what point performance becomes impaired.

No studies have been found to indicate how much time firefighters need to fully recover following a shift. In fact, no studies were found that had tracked recovery time for 24-hour shifts. Within the firefighting profession, one to two days of recovery time is typical provided for 24-hour shift schedules and up to four days for 48-hour shift schedules. Considering, Totterdell et al. (1995) found that three or more days may be necessary for shift working nurses to fully recover and Akerstedt et al. (2000) found that as many as six days may be needed for full recovery of construction workers on 12-hour shifts, it is likely that one day is not sufficient for firefighters working 24-hour shifts. Two recovery days may be sufficient, but this needs to be verified by research.

Research suggests that repeated, insufficient recovery from occupational fatigue may be the critical link that leads to adverse psychological and physiological problems (De Croon, Sluiter, & Frings-Dresen, 2003; Sluiter, Van der Beck, & Frings-Dresen, 1999). In a study of air traffic controllers, Repetti (1989), found highly demanding shifts are associated with increased social withdraw and expressed anger. This may indicate cognitive fatigue, which requires additional recovery time. These same symptoms have been observed in firefighters (Kirshman, 2004). Additionally, there is substantial research that has connected poor physical and mental health of firefighters to working conditions.

Determining adequate recovery time for firefighters may have a substantial impact on their physical and mental health.

Demographics and Biometric Measures

Fatigue research in other fields has indicated that demographic and biometric variables may also influence the extent of fatigue reported (subjective measures) or experienced (objective measures). Demographic. Factors such as age, gender, and ethnicity have been found to be relevant variables in other studies (Akerstedt et al., 2017; Lombardi, Folkard, Willetts, & Smith, 2010; Lu, Sesek, Megahed, & Cavuoto, 2017).

Body Mass Index has been found to increase the risk of heat related disorders (Brake & Bates, 2001), affect sleep quality (Knutson & Van Cauter, 2008; Patterson et al., 2010), increased heart rate (Dennison, Mullineaux, Yates, & Abel, 2012), and increased risk of work injuries (Lombardi et al., 2010). Body Mass Index is calculated from height and weight using the following equation:

$$BMI = kg/m2$$

where kg is a person's weight in kilograms and m2 is their height in meters squared.

Biometric information such as heart rate (Brake & Bates, 2001; Minard, 1973; Morley et al., 2012), body temperature (Knauth, Rutenfranz, Herrmann, & Poppel, 1978; Morley et al., 2012; Rosa & Colligan, 1988), and pupil dilation (Cavuoto & Megahed, 2017; Yung et al., 2014; Takeyama et al., 2005), have previously been used to identify fatigue in workers. Other biometric factors that may be relevant include blood sugar (Caplan, Cobb, John R. P. Jr., Harrison, & S. R. Jr., 1975), blood pressure (Choi et al., 2016), and Body Mass Index (BMI) (Brake & Bates, 2001; Caruso, Hitchcock, Dick, Russo, & Schmit, 2004; Kales, Polyhronopoulos, Aldrich, Leitao, & Christiani, 1999).

These factors may be important for recognizing those who may be at greater risk for experiencing fatigue due to their bodies already working harder, however, not all are practical for a field study.

Heart rate is an indicator of how hard the body is working. Morley et at. (2012) found that heart rate increases significantly during physical labor in hot environments. Brake & Bates (2001), explain that heart rate is a good indicator of both physical and mental stress. Minard (1973), found that a workers' performance becomes impaired when the mean heart rate, across the course of an eight-hour shift, is above 120 beats per minute.

Body temperature has been found to be relevant in several studies. Morley et. al. (2012) used thermal sensing devices that were swallowed by firefighters, to show that internal temperatures increase significantly during short-term, heavy physical activity. In more extensive studies, Rosa and Colligan (1988) found that oral temperatures were higher on days of work, than on rest days. Knauth, Rutenfranz, Herrmann, & Poppel (1978) found that two recovery days are needed for rectal temperature to return to baseline following working two consecutive night shifts. The findings have been consistent, despite a variety of methods for obtaining the information. For field research, as well as ease of gaining participation, temporal or infrared temperatures would be most appropriate for field study. Table 2-1, below, shows the variables and findings from previous studies.

Table 2-1 Variables and Results from Previous Literature

Variable	**Findings**	**Literature**

Race/Ethnicity	Significant difference between race/ethnicities	National Safety Council, 2019; Akerstedt et al., 2017; Lombardi et al., 2010; Lu et al., 2017
Gender	Women report significantly higher SSR than men	Akerstedt et al., 2017; Lombardi et al., 2010; Lu et al., 2017
Age	Age correlated with significantly higher SSR Age correlates with increased weight	Akerstedt et al., 2017; Lombardi et al., 2010; Lu et al., 2017 Knutson &Cauter, 2008
Body Mass Index (BMI)	Increased BMI correlates with sleep loss. BMI predicts fatigue	Brake & Bates, 2001 Caruso et al., 2004; Kales et al., 1999
Body Temperature (BT)	No significant difference b/w BT ToD. Significant difference in BT b/w on shift and off shift days. BT Significantly correlated with increased workload	Takeyama et al., 2005 Knauth et al., 1978; Rosa and Colligan, 1988 Morley et al., 2012
Heart Rate (HR)	Significant difference b/w ToD results for HR. HR Significantly correlated with increased workload Performance impairment when heart rate exceeds 120 bpm Increased HR affects Cognitive Performance.	Takeyama et al., 2005 Brake & Bates, 2001 Minard, 1973 Cavuoto & Megahed, 2017; Yung et al., 2014; Dennison et al., 2012
Workload	BT Significantly correlated with increased workload HR Significantly correlated with increased workload	Morley et al., 2012 Brake & Bates ,2001; Morley et al., 2012
On Shift	Significant difference in BT b/w on shift and off shift days.	Rosa and Colligan, 1988

Time of Day (ToD)	Significant difference b/w ToD results for SQn. Significant difference b/w ToD results for SSR. No Significant difference b/w ToD results for SSR. Significant difference b/w ToD results for HR. Significant difference b/w ToD results for SFR. Significant difference b/w ToD results for RT.	Paley & Tepas, 1994 Takeyama et al., 2005 Paley & Tepas, 1994 Takeyama et al., 2005 Takeyama et al., 2005 Takeyama et al., 2005
Time on Task (ToT)	No significant difference b/w ToT and SSR. Significant difference b/w RT results for ToT	Paley & Tepas, 1994 Kujawski et al., 2018
Sleep Quantity (SQn)	Significant difference b/w ToD results for SQn. Significant difference b/w RT results for SQn.	Paley & Tepas, 1994 Armstrong et al., 2013; Kujawski et al., 2018; Balkin et al., 2011; Dinges et al., 1997; Dorrian et al., 2005; Stout et al., 2020; Williams et al., 2011
Sleep Quality (SQl)	SQl correlated with significantly higher SSR	Akerstedt et al., 2017
PVT Mean Response Time (RT)	Significant difference b/w ToD results for RT. Significant difference b/w RT results for SQn. Significant difference b/w RT results for ToT No significant correlated between SFR and RT.	Takeyama et al., 2005 Armstrong et al., 2013; Balkin et al., 2011; Dinges et al., 1997; Dorrian et al., 2005; Stout et al., 2020; Williams et al., 2011; Conner et al., 2002; Cummings et al., 2001; Hursh et al., 2004; Landrigan et al., 2004; Lockley et al., 2004; Patterson et al., 2010 Kujawski et al., 2018 Horne & Baulk, 2004; Kaplan et at., 2007; Lockley et al., 2007; Scott et al., 2007, Powell and

	Significant effect for ToD on RT	Copping, 2016 Armstrong et al., 2013 Mountain et al., 2007
PVT Mean Total Errors (TE)	Significant difference b/w TE results for ToT RT decreased while TE increased TE increase with ToT TE increases with decrease in sleep	Armstrong et al., 2013 Grego et al., 2005; Fan & Smith, 2017; Morley et al., 2012 Folkard & Lombardi, 2006; Mitchell & Williams, 2000 Cummings et al., 2001; Conner et al., 2002
Subjective Sleepiness Rating (SSR)	Significant difference b/w ToD results for SSR. No Significant difference b/w ToD results for SSR. No significant difference b/w ToT and SSR.	Takeyama et al., 2005 Paley & Tepas, 1994 Paley & Tepas, 1994
Subjective Fatigue Rating (SFR)	Significant difference b/w ToD results for SFR. No significant correlation between SFR and RT No significant correlated between SFR and RT.	Takeyama et al., 2005 Armstrong et al., 2013 Horne & Baulk, 2004; Kaplan et at., 2007; Lockley et al., 2007; Scott et al., 2007, Powell and Copping, 2016

DV – Dependent Variable; IV – Independent Variable

For this study to be comparable to others, this same information was collected. Additionally, information was collected on shift structure and time in profession to determine if these factors have an impact on the results.

Conclusion

Limited studies that have focused on cognitive function of fatigued firefighters (Armstrong et al., 2013; Greenlee et al., 2014; Kujawski et al., 2018; Morley et al., 2012;

Paley & Tepas, 1994; Takeyama et al., 2005). Those that have focused on cognitive function have taken place within laboratory, simulated work environments, or work settings which were not representative of the combined physiological and psychological strain that a firefighter may be exposed to repeatedly during the course of a shift. Additionally, no studies were found to evaluate the time needed extent of recovery between shifts worked by firefighters to determine if adequate recovery time is provided between shifts. Therefore, research is needed to document the impact fatigue has on the cognitive performance of firefighters working 24- and 48-hour shifts. Research should also evaluate the extent of cognitive performance recovery occurring between rotations of these shifts within both shift structures.

CHAPTER III

METHODOLOGY

Overview

Based on research gaps identified in the previous chapter, this study sought to document the impact of fatigue on the cognitive performance of firefighters working 24- and 48-hour shifts and evaluate the extent of recovery occurring between those shifts. This study relied on quantitative, non-experimental methods to collect and analyze data.

Research Questions and Hypotheses

RQ1: What are the associations between PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night) for firefighters working 24 and 48-hour shifts?

RQ2: Is there a difference between Cognitive Performance (PVT Mean Response Times and PVT Total Errors) on and off shift for firefighters working 24 and 48-hour shifts?

RQ3: Is there a difference between Sleep Quantity and Quality obtained on and off shift for firefighters working 24 and 48-hour shifts?

RH1: There will be significant changes between PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings, and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).

RH2: Age, BMI, Resting Heart Rate. Total Sleep Quantity, Mean Sleep Quality and Workload will be significantly correlated with PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings, and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).

RH3: Participants with different shift structures (i.e., 24 or 48-hour shifts) will have significantly different PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).

RH4: Participants who have different years of experience in the fire service will have significantly different PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).

RH5: The biomathematical SAFTE model will reveal a significant relationship between predicted effectiveness and actual effectiveness (cognitive performance) of firefighters working 24 and 48-hour shifts?

Data Collection

Participants

A convenience sample was used, consisting of fire departments that were willing to allow the study to take place in-situ, during normal work activities. Analysis was limited to career firefighters, who have been on the job for at least one full month and whose shifts were 24 or 48-hours in length. All firefighters participating in this study were municipal/structural firefighters located in Arkansas, Oklahoma, Missouri, Georgia, and Texas. In lieu of direct participant compensation, a donation was made in the name of each participating municipality to the National Fallen Firefighters Foundation for each firefighter on each day that all data entry points were completed. Information was collected for fourteen days, which accounted for up to six rotations through a shift schedule for those working 24-hour shifts and up to three rotations for those working 48-hour shifts.

Variables

Data was collected from firefighters via three methods: initial survey, electronic journal, and psychomotor vigilance task. The following subsections detail how which data was collected via each method and how each method was conducted.

Initial Survey. Participants were asked to complete a short survey on the day they signed up for the study (the day before the first day of the study). It collected the demographic information (Age, Ethnicity, Gender, Shift Structure, and Years in Service) and some of the biometric information (Resting Heart Rate, Height, and Weight). Additionally, participants were asked to provide the serial number from the watch they were issued to ensure data could be matched between participant journal responses and Zulu watch data. The initial survey was delivered electronically via text as a means of testing the contact information provided by participants prior to receipt of daily journal links.

The Height and Weight information collected by the initial survey was used to calculated Body Mass Index using the following equation:

$$BMI = kg/m^2$$

where kg is a person's weight in kilograms and m^2 is their height in meters squared. The workload variable was calculated use the following equation:

$$CHREEE= [HR – HRrest + 15) / (HRmax – HRrest +15)]100$$

Where HR is heart rate, HRrest is resting heart rate, and HRmax is maximum heart rate. Maximum heart rate is determined by subtracting the participant’s age from 220, for example a maximum heart rate for a 20-year-old person is 200 (American Heart Association, 2015). Resting heart rate was obtained via the initial survey. Heart rate was obtained at four points throughout each day. Maximum heart rate was calculated based off of age provided in the initial survey. Workload was calculated for each time data was collected (i.e., Morning, Noon, Afternoon, and Night).

Electronic Journal. The electronic journal data was also collected via electronic link sent to participants phones four times daily. This data included whether or not the participant was on shift, working a second job, their body temperature, heart rate, subjective rating of sleepiness, and subjective rating of fatigue. Participants were instructed to obtain their heart rate by holding a button on the side of the Zulu watch. They then typed the rate into the response field on the electronic journal. Subjective Fatigue Ratings were measured using the Samn-Perelli 7-point fatigue scale. The journal question was presented as follow:

"How would you rate your current fatigue? (Choose the one that most closely describes how you feel)."

Fully alert, not tired			A little tired, less than fresh			Completely exhausted, unable to function effectively
1	2	3	4	5	6	7

Subjective Sleepiness Ratings were measured using the Karolinska Sleepiness Scale. The journal question was presented as follow:

How would you rate your current sleepiness? (Choose the one that most closely describes how you feel):

Extremely alert, not sleepy		Alert		Neither alert nor sleepy		Sleepy, but no effort to stay awake		Very sleepy, great effort to keep stay awake
1	2	3	4	5	6	7	8	9

Psychomotor Vigilance Test. The PVT was conducted via electronic link sent to participants' cell phones four times daily. It was used to track diminishing cognitive performance. The service used to conduct the PVT was Inquisit by Millisecond. The day before the study began, participants were sent a link to ensure the test would operate properly on their phone. Prior to leaving the recruitment meeting, participants were asked to complete one PVT to ensure they understood how to complete the task and that it would operate properly on their phone. These “practice tests” were not recorded in the dataset for this study.

Participants were instructed to lay their phone on their lap or a table in front of them in the horizontally position and remain seated while completing all PVT tasks. Additionally, they were told to use a “click’ motion to tab the spacebar, not a “swiping motion” as the swiping motion may cause the test to close. They were informed that the test would take 8 minutes each time it is conducted and they would be presented with a stimulus at random intervals every 2-10s. They were also provided the following summary of the test: “The test will be a white screen, upon which a red stop watch will appear at random intervals, when the stopwatch appears tap the space bar at the bottom of the screen as quickly as you can. A valid response (response occurs after stopwatch appears) is followed by reaction time feedback. An invalid response (response occurs before stopwatch appears) is followed by a brief error message” (Borchert, 2017).

To start the test, participants were instructed to click the link provided in a text message from the Principal Investigator. This link took them to a home screen and provided a brief countdown before beginning the test. The home screen also included directions on completing the task. Once the countdown concluded a spacebar appeared at the bottom of the screen and the test began. The PVT software collected the following information for each iteration of the test:

1. Participant ID# - this a three-digit number assigned to the participant at the initial meeting. If the participant forgot their number, it could be retrieved from their text messages related to the study.
2. Elapsed Time – It is measured from onset to offset of script. It is reported in milliseconds.
3. Mean response time – The mean of all valid responses
4. Max RT - The maximum valid response time; reported in milliseconds.
5. Min RT - The minimum valid response time; reported in milliseconds.
6. Lapse – The number of valid responses with latency > 500ms.
7. False Start – The number of responses that occurred before the target appeared.

Zulu Watch. Participants wore a validated actigraphy sleep-tracking device (Zulu Watch, provided by the Institutes for Behavior Resources) continuously for up to two weeks. Activity data were collected in two-minute epochs and were automatically scored as on-wrist or off-wrist. Off-wrist data was not counted as sleep. Additionally, sleep-wake determination was made and classified as 0=Awake, 1=Interrupted, 2=Light Sleep, and 3=Deep Sleep (Devine et al., 2020). Devices were programmed to detect multiple sleep episodes per day. There was no maximum parameter, however a minimum sleep detection was set at 20 minutes. Data was downloaded using the Zulu Data Extraction application (Institutes for Behavior Resources, Version 2.0) and exported to CSV files. Files reported all sleep interval start and end times, sleep duration in minutes, and sleep efficiency as a percentage.

This study included a variety of measures found to be relevant in other studies. Due to insufficient data available for valid comparison on gender, ethnicity, and body temperature, these variables were eliminated from analysis. The types, classifications, and methods of measuring each of the remaining variables are summed up in Table 3-1 below.

Table 3-1: List of Variables, Types, Classifications, and Methods of Calculation

Variable	**Type**	**Classification**	**Method**
Age	IV	Scale	Reported
Shift Structure	IV	Nominal	Reported
Years of Service	IV	Scale	Reported
On/Off Shift	IV	Nominal	Reported
Working at Second Job	IV	Nominal	Reported
Resting Heart Rate	IV	Scale	Reported
Body Mass Index (BMI)	IV	Scale	BMI = kg/m2
Heart Rate	IV	Scale	Reported
Workload	IV	Scale	$[HR - HR_{rest} + 15) / (HR_{max} - HR_{rest} + 15)]100$
PVT Mean Response Time	DV	Scale	Mean value of valid responses
PVT Total Errors	DV	Scale	Total number of all responses > 500ms + number of false starts
Subjective Fatigue Rating	DV	Ordinal	1-7 Scale
Subjective Sleepiness Rating	DV	Ordinal	1-9 Scale

Analytical Approaches

Though participants were requested to provide heart rate, body temperature, and subjective ratings of sleepiness and fatigue four times daily, participants rarely reported body temperature. This variable was, therefore, excluded from analysis. The sample included inadequate number of female and races other than white for valid comparison. The variables Gender and Ethnicity were, therefore, excluded from analysis. Additionally, participants were grouped by years of experience (0-10, 11-20, and 20-35) for comparison. The group with 20-35 years of experience was too small for valid comparison (n=16) and therefore was not included in analysis of differences between groups with different years of experience. Their data was included in all other analysis that did not require grouping by years of experience. All other variables were adequate for the statistical approaches of this study.

Pearson correlation analysis was used to test RQ1 and RH2. Correlation analysis was used to evaluate relationships between biometric, sleep, and work factors and cognitive function. Factors evaluated include objective measures of fatigue (PVT Mean Response Time and PVT Total Errors), age, BMI, resting heart rate, total sleep quantity, mean sleep quantity, and workload. Additionally, correlations between the objective measures of fatigue and subjective measures of fatigue and sleepiness were evaluated.

Independent Sample T-test was used to evaluate RQ2, RQ3, RH3, and RH4. For RQ2 the mean values of the cognitive performance variables (PVT Mean Response Time and PVT Total Errors) were compared for on and off shift days to determine if there are significant differences in cognitive performance on days off. For RQ3 these mean values of Total Sleep Quantity and Mean Sleep Quality were compared for on and off shift days to determine if there is a significant difference in the quantity and quality of sleep obtained during off shift days. RH3 and RH4 compared the PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night) to determine if there are differences for groups with different shift structures or years of service.

Repeated Measures ANOVA was used to evaluate RH1 in order to compare the objective of cognitive performance with the subjective measures of fatigue and sleepiness to determining if firefighters were able to recognize when they are at risk for cognitive function impairment. Mauchly's Test of Sphericity and additional post-Hoc testing was also conducted on this data.

Finally, the SAFTE model used linear regression to evaluate RH5. The biomathematical fatigue model (SAFTE) was used to predict cognitive performance using sleep opportunities and time of day during the two weeks in which data was collected from firefighters. The predictions were then compared to actual effectiveness using Linear Regression, to validate the use of the SAFTE model as a predictive tool in identifying firefighter fatigue. Total sleep time across the 24-hour day (TST24) was monitored continuously throughout a 2-week study period in firefighters working 24 and 48-hour shifts using a sleep-tracking actigraphy device (Zulu Watch, Institutes for Behavior Resources). Speed on an 8-minute PVT was assessed daily on on-shift and off-shift days. This information was then combined into a single file and entered into the SAFTE software package. Actigraphy-based sleep episodes were predominately used, however, predicted sleep was entered when valid actigraphy data was not available. The data was then processed to produce a continuous record of model-predicted effectiveness for each participant.

Because this was a field study, baseline PVT results could not be obtained for each individual. To establish a “baseline” all PVT sessions were rank ordered by mean speed, then the median was obtained for the top 10% highest speeds for each individual. “This metric cannot assume that the individual is “well-rested,” as in a laboratory study baseline, but like a laboratory study, this baseline still represents “typical best” performance (TBP) with ample room for fatigue-induced decrements and countermeasure-induced improvements”(Roma et al., 2012). Mean speeds >2 standard deviations above the grand distribution were excluded. The Predicted Effectiveness was computed as a percentage of the median of an individual’s top 10% fastest PVT Speeds ((Mean Reaction Time/TBP Mean Reaction Time) *100).

The Actual Effectiveness score ([1/Reaction Time] expressed as a %) was compared to the Predicted Effectiveness score to the nearest 30-minute interval from the respective participant’s file. All test session results were organized into 5% SAFTE Predicted Effectiveness bins (<65%, 65-70%, 70-75%, 75-80%, 80-85%, 85-90%, 90-95%, 95-100%, >100%), and the relationship between mean SAFTE prediction and mean PVT performance across bins was quantitatively assessed to explore correlation of Predicted Effectiveness to Actual Effectiveness across the 5% Effectiveness bins.

CHAPTER IV

FINDINGS

Overview

This chapter describes the analysis conducted and displays the empirical results to examine the hypotheses of this research. Analysis was conducted using SPSS Software, version 28.0.0.0. (IBMCorp, 2021) Table 4-1, below, shows the list of primary and secondary variables in this study with their relative scales. Secondary variables are the mean value of the primary variables.

Table 4-1: List of Primary and Secondary Variables and Scales

Secondary Variable [a]	Primary Variable	Number of Primary Variables	Scale
	Ethnicity		Dichotomous: 1 = White; 2 = Other
	Shift Structure		Dichotomous: 0 = 24 hours; 1 = 48 hours
	Years in Fire Service (Group)		Categories: 1=0-5; 2=6-10; 3=11-15; 4=16-20; 5=21-35
	Years in Fire Service		Continuous
	Age		Continuous
	BMI		Continuous
	Resting Heart Rate		Continuous
Total Sleep Quantity	TotalSleepQuantity.1.7 thru TotalSleepQuantity.1.18	18	Continuous
Mean Sleep Quality	MeanSleepQuality.1.7 thru MeanSleepQuality.1.18	18	Continuous

Workload	Workload.2.1, Workload.2.2, Workload.2.3, Workload.2.4 thru Workload.18.1, Workload.18.2, Workload.18.3, Workload.18.4	72	Continuous
On Shift	OnShift.2.1 thru OnShift.18.1	18	Continuous
PVT Mean Response Time at Morning	PVTMeanRT.2.1 thru PVTMeanRT.18.1	18	Continuous
PVT Mean Response Time at Noon	PVTMeanRT.2.2 thru PVTMeanRT.18.2	18	Continuous
PVT Mean Response Time at Afternoon	PVTMeanRT.2.3 thru PVTMeanRT.18.3	18	Continuous
PVT Mean Response Time at Night	PVTMeanRT.2.4 thru PVTMeanRT.18.4	18	Continuous
Total Errors at Morning	TotalErrors.2.1 thru TotalErrors.18.1	18	Continuous
Total Errors at Noon	TotalErrors.2.2 thru TotalErrors.18.2	18	Continuous
Total Errors at Afternoon	TotalErrors.2.3 thru TotalErrors.18.3	18	Continuous
Total Errors at Night	TotalErrors.2.4 thru TotalErrors.18.4	18	Continuous
Subjective Fatigue Rating at Morning	SubjectiveFatigueRating.2.1 thru	18	Continuous
Subjective Fatigue Rating at Noon	SubjectiveFatigueRating.2.2 thru SubjectiveFatigueRating.18.2	18	Continuous
Subjective Fatigue Rating at Afternoon	SubjectiveFatigueRating.2.3 thru SubjectiveFatigueRating.18.3	18	Continuous
Subjective Fatigue Rating at Night	SubjectiveFatigueRating.2.4 thru SubjectiveFatigueRating.18.4	18	Continuous
Subjective Sleepiness Rating at Morning	SubjectiveSleepinessRating.2.1 thru SubjectiveSleepinessRating.18.1	18	Continuous
Subjective Sleepiness Rating at Noon	SubjectiveSleepinessRating.2.2 thru SubjectiveSleepinessRating.18.2	18	Continuous
Subjective Sleepiness Rating at Afternoon	SubjectiveSleepinessRating.2.3 thru SubjectiveSleepinessRating.18.3	18	Continuous
Subjective Sleepiness Rating at Night	SubjectiveSleepinessRating.2.4 thru SubjectiveSleepinessRating.18.4	18	Continuous

[a]: Secondary variables are hypothesized variables and are calculated by mean values of their related primary variables

The description of the research questions and applied statistical tests are represented in Table 4-2.

Table 4-2: List of Research Questions/Hypotheses and Statistical Tests

Research Question	**Statistical Test**
RQ1: What are the associations between PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night) for firefighters working 24 and 48-hour shifts?	Pearson Correlation r
RQ2: Is there a difference between Cognitive Performance (PVT Mean Response Times and PVT Total Errors) on and off shift for firefighters working 24 and 48-hour shifts?	Independent Sample T-test
RQ3: Is there a difference between Sleep Quantity and Quality obtained on and off shift for firefighters working 24 and 48-hour shifts?	Independent Sample T-test
RH1: There will be significant changes between PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings, and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).	Repeated Measures ANOVA/ Mauchly's Test of Sphericity & Post-Hoc Testing
RH2: Age, BMI, Resting Heart Rate. Total Sleep Quantity, Mean Sleep Quality and Workload will be significantly correlated with PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings, and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).	Pearson Correlation r
RH3: Participants with different shift structures (i.e., 24 or 48-hour shifts) will have significantly different PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).	Independent Sample T-test
RH4: Participants who have different years of experience in the fire service will have significantly different PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at different times of the day (i.e., morning, noon, afternoon, night).	Independent Sample T-test
RH5: The biomathematical SAFTE model will reveal a significant relationship between predicted effectiveness and actual effectiveness (cognitive performance) of firefighters working 24 and 48-hour shifts?	Linear Regression

Data Screening

A total of 254 full-time, professional firefighters, working 24-hour or 48-hour shifts, participated in this study between September 2020 and August 2021. Many participants provided incomplete date. All data was screened to ensuring it was correctly entered and free from large missing values, outliers, and to confirm the distribution was normal for continuous variables. Little and Schluchter (1985) stress that missing data up to 5% may not cause serious problems in the interpretation of findings; missing data beyond 5% may affect the accuracy of the results. Missing values of less than 5 percent are considered within reasonable limits (Hair, Sarstedt, Ringle, & Gudergan, 2017). The screening of the data indicated 123 cases were missing more than 5% of the data needed for analysis. The remaining 131 cases included data sets that were missing less than 2% data for all variables.

Next, the data was reviewed for outliers. Outliers are observations with a unique combination of characteristics identifiable as distinctly different from the other observations (Hair et al. 1998). Checking for outliers is important, as outliers could affect the normality of the data, which could then distort the statistical results (Hair et al. 1998; Tabachnick and Fidell 2007). Besides examining histograms and box-plots, each variable was examined for the standardized (z) score. According to Hair et al., (1998) for small sample size, Absolut (z) > 4 is evidenced of an extreme observation. Therefore, any Z-score greater than 4 or less than -4 are considered outliers. As shown in Table 4-3 below, the upper bound standardized (z) score was above the cut off of 4 for some items. The corresponding cases #12, #23, #79, #92, #108, #170 and #265, which included outliers that pushed the standardized (z) scores beyond the upper bound, were eliminated from the data set and reduced the sample size from 131 to 124.

Table 4-3: Results of Univariate Outlier based on Standardized Values

Day Time	Variable	Initial Standardized value (Z-Score) (n=131)		Second Standardized value (Z-Score) after deleting 7 cases (n=124)	
		Lower Bound	Upper Bound	Upper Bound	Upper Bound
Entire	Years in Fire Service	-1.334	2.861	-1.287	2.833

	Age	-1.915	2.422	-1.926	2.383
	BMI	-1.796	3.257	-1.774	3.235
	Resting Heart Rate	-2.521	2.864	-2.516	2.849
	Total Sleep Quantity	-3.840	2.345	-3.782	2.317
	Mean Sleep Quality	-1.482	**10.204**	-3.237	1.841
	Workload	-1.886	2.595	-1.888	2.570
	On Shift	-2.748	**4.392**	-2.885	3.427
Morning	PVT Mean Response Time	-0.153	**11.356**	-3.853	2.645
	Total Errors	-1.497	2.860	-1.505	2.954
	Subjective Fatigue Rating	-2.301	1.836	-2.329	1.822
	Subjective Sleepiness Rating	-2.168	2.035	-2.166	2.014
Noon	PVT Mean Response Time	-3.141	**4.587**	-1.364	3.024
	Total Errors	-1.353	**4.110**	-1.310	3.338
	Subjective Fatigue Rating	-2.116	3.164	-2.073	3.109
	Subjective Sleepiness Rating	-2.011	3.174	-1.979	3.117
Afternoon	PVT Mean Response Time	-3.084	**4.225**	-3.450	3.404
	Total Errors	-1.538	3.051	-1.542	3.081
	Subjective Fatigue Rating	-3.164	2.519	-2.105	2.545
	Subjective Sleepiness Rating	-2.728	2.726	-1.932	2.737
Night	PVT Mean Response Time	-2.842	**4.001**	-3.164	3.901
	Total Errors	-1.495	3.291	-1.507	3.361
	Subjective Fatigue Rating	-3.348	2.854	-2.239	2.935
	Subjective Sleepiness Rating	-2.866	2.813	-1.916	2.881

The standardized (z) scores were computed for the remaining 124 cases after the elimination. The results indicated that the standardized (z) scores of the remaining cases for the continuous variables ranged between -3.782 and 3.901, indicating none of the remaining variable exceeded the threshold of ±4. Thus, there are no outliers among the remaining 124 cases.

Assessment of Normality

The normality test was run, using Kolmorove-Smirnov (K.S) test, to determine whether the data set of the continuous variables was well-modelled by a normal distribution or not. The K.S p-value above the standard significant level of 0.05 represents a normal distribution of the data. Field (2009) suggested that in the condition of violation the assumption of normality due to significant K.S p-value, it would be sufficient just to inspect the value of the skewness and kurtosis, and virtually observe the shape of the distribution. For this reason, skewness and kurtosis were employed to assess normality of this data. As a general rule of thumb, the data may be assumed to be normally distributed if skew and kurtosis is within the range of -1 to +1, or -2 to +2 or even 3 (Schumacker & Lomax, 2010). Byrne, 2006 suggested using a cut-off point of less than 7 as an acceptable value for the kurtosis. She added that the data which is skewed within the range of -2 to +2 could be considered as being normally distributed. Table 4-4 demonstrates the results of normality test for the continuous variables.

Table 4-4: Results of Normality Test

Day Time	**Variable**	**Kolmogorov-Smirnov**	**Skewness (≤±2)**	**Kurtosis (≤±7)**
Entire	Years in Fire Service	0.102^{**}	0.941	0.57
	Age	0.076	0.264	-0.649
	BMI	0.09^{*}	0.761	0.49
	Resting Heart Rate	0.068	0.129	-0.021
	Total Sleep Quantity	0.068	-0.704	0.991
	Mean Sleep Quality	0.059	-0.407	0.004
	Workload	0.066	0.309	-0.721
	On Shift	0.149^{***}	0.628	0.902
Morning	PVT Mean Response Time	0.119^{***}	-0.211	2.634
	Total Errors	0.126^{***}	0.728	-0.205
	Subjective Fatigue Rating	0.074	-0.224	-0.724
	Subjective Sleepiness Rating	0.064	-0.046	-0.777
Noon	PVT Mean Response Time	0.148^{***}	1.179	0.601
	Total Errors	0.151^{***}	1.038	0.508
	Subjective Fatigue Rating	0.069	0.17	-0.247
	Subjective Sleepiness Rating	0.06	0.391	-0.11

Afternoon	PVT Mean Response Time	0.159***	0.985	2.395
	Total Errors	0.132***	0.927	0.293
	Subjective Fatigue Rating	0.062	0.299	-0.23
	Subjective Sleepiness Rating	0.086*	0.399	-0.383
Night	PVT Mean Response Time	0.152***	0.827	3.136
	Total Errors	0.124***	0.924	0.509
	Subjective Fatigue Rating	0.078	0.386	-0.019
	Subjective Sleepiness Rating	0.085*	0.47	0.007

N=124; *p< 0.05, **p< 0.01, ***p< 0.001

As shown in Table 4-4, the result of Kolmogrov Smirnov test of normality indicated that the data sets of some variables were not normally distributed because of having p-values less than the standard significance level of 0.05. Nevertheless, the results of assessing deviation from normality showed that the value of skewness for the variables ranged between -0.704 and 1.179, within the acceptable range of ±2. The results also indicated that the kurtosis value of the variables ranged between -0.777 and 3.136, within the acceptable range of ±7. Therefore, it can be concluded that the data set of all variables have normal distribution (Byrne, 2006).

Sample

Of the 124 participants who provided sufficient data for analysis, 103 respondents identified as white (83.1%), and 21 from others ethnicities (16.9%). Though the sample is predominantly white, this is consistent with the Bureau of Labor Statistics' (BLS) 2021 records, which indicate the fire service is 84.3% white. Females were slightly under represented in the sample with only 4 respondents identifying as female (3.2%), while 120 respondents identified as male (96.8%). According to the BLS records the fire service was 5.1% female and 94.9% male in 2021. The mean age was 38 years old (range 22-57). While the mean time in the fire service was 11 years (range, 0.5-35). In specifying the years of experience in the fire service, 52.5% of participants had 0 – 10 years of experience, 34.6 had 11 – 20 years of experience, and 12.9% had 21 – 35 years of experience. Table 4-5 shows frequencies and percentages of categorical variables.

Table 4-5: Sample Profile

Demographical Variable	Frequency	Percentage
Ethnicity		
White	103	83.1
Others	21	16.9
Gender		
Male	120	96.8
Female	4	3.2
Shift Structure		
24 hours	96	77.4
48 hours	28	22.6
Years in Fire Service		
0 – 10 years	65	52.5
11 – 20 years	43	34.6
21 – 35 years	16	12.9

N=124

Descriptive Statistics for Continuous Variables

The descriptive statistic of the continuous variables was examined next. The mean was applied as a measure of central tendency, while the standard deviation was applied as a dispersion index to indicate the degree to which individuals within each variable differ from the variable mean. Table 4-6 demonstrates the results of descriptive statistic of the continuous variables.

Table 4-6: Results of Descriptive Statistics of Continuous Variables

Day Time	Variable	Missing#	Missing %	Mean	Standard Deviation	Min	Max
Entire	Years in Fire Service	0	0%	11.280	8.373	1	35
	Age	0	0%	37.650	8.123	22	57
	BMI	0	0%	29.440	4.812	21	45
	Resting Heart Rate	0	0%	66.200	10.810	39	97

	Total Sleep Quantity	0	0%	415.887	52.606	216.91	537.75
	Mean Sleep Quality	0	0%	87.705	2.919	78.26	93.08
	Workload	0	0%	17.572	4.786	8.54	29.87
	On Shift	0	0%	0.389	0.139	0.11	1
Morning	PVT Mean Response Time	2	2%	440.837	98.585	300.14	731.46
	Total Errors	2	2%	9.873	6.383	0.78	28.78
	Subjective Fatigue Rating	0	0%	3.293	0.937	1.11	5
	Subjective Sleepiness Rating	0	0%	4.061	1.310	1.22	6.7
Noon	PVT Mean Response Time	0	0%	445.318	117.879	284.57	801.81
	Total Errors	0	0%	10.298	7.250	0.8	34.5
	Subjective Fatigue Rating	0	0%	2.733	0.836	1	5.33
	Subjective Sleepiness Rating	0	0%	3.158	1.090	1	6.56
Afternoon	PVT Mean Response Time	1	1%	457.250	125.417	288.89	901.13
	Total Errors	1	1%	10.759	6.882	0.46	32
	Subjective Fatigue Rating	0	0%	2.811	0.860	1	5
	Subjective Sleepiness Rating	0	0%	3.276	1.178	1	6.5
Night	PVT Mean Response Time	2	2%	473.965	135.756	289.52	1041.24
	Total Errors	2	2%	11.640	7.518	1	37
	Subjective Fatigue Rating	0	0%	3.083	0.881	1.11	5.67
	Subjective Sleepiness Rating	0	0%	3.716	1.244	1.33	7.3

N=124

Research Question 1

Pearson correlation was used to test the relationship between the mean values of the continuous variables in this study. The statistical significance of the correlation results follows the conventional approach (two-tailed, and a $p < 0.05$ was considered statistically significant). In interpreting the strength of the relationship based on the r coefficient, Hemphill (2003) recommendation was used. The relationship between variables can be described as very weak if the correlation coefficient (r) ranges from 0.01 to 0.19, weak if ranges from 0.20 to 0.39, moderate if ranges from 0.40 to 0.59, strong if ranges from 0.60 to 0.79, and very strong if the correlation coefficient ranges from 0.80 to 1.0. Table 4-7 shows the correlations between the mean values of the PVT Mean Response Times, mean value of PVT Total Errors, mean value of Subjective Fatigue Ratings and mean value of Subjective Sleepiness Ratings for each time of the day: morning, noon, afternoon and night.

As shown in Table 4-7, the results indicated the objective measures (PVT Mean Response Time and Total Errors) are significantly and positively correlated at all times of the day; Morning: $r = 0.871$, $p < 0.001$, very strong; Noon: $r = 0.907$, $p < 0.001$, very strong; Afternoon: $r = 0.848$, $p < 0.001$, very strong and Night: $r = 0.760$, $p < 0.001$, strong. The Subjective Ratings (for both sleepiness and fatigue) also had significant, and very strong positive correlations with each other at all times of the day Morning: $r = 0.941$, $p < 0.001$; Noon: $r = 0.930$, $p < 0.001$; Afternoon: $r = 0.928$, $p < 0.001$ and Night: $r = 0.877$, $p < 0.001$. The Subjective Ratings were not correlated with Response Times at any time of the day. Total Errors had significant and positive, but weak correlations with the Subjective Sleepiness on at Noon: $r = 0.195$, $p < 0.05$ and Afternoon: $r = 0.302$, $p < 0.01$. Total Errors also had significant and positive, but weak correlations with the Subjective Fatigue during the same time periods; Noon: $r = 0.196$, $p < 0.05$ and Afternoon: $r = 0.214$, $p < 0.05$.

Table 4-7: Results of Pearson Correlation between PVT Mean Response Time, Total Errors, Subjective Fatigue Rating & Subjective Sleepiness Rating at Four Times a Day

Day Time	Variable		(1)	(2)	(3)
Morning	PVT Mean Response Time (1)	r	**1**		
	Total Errors (2)	r	**0.871*** **	**1**	
		Magnitude	Very Strong		
	Subjective Fatigue Rating (3)	r	0.077	0.168	**1**
		Magnitude	Very Weak	Very Weak	
	Subjective Sleepiness Rating (4)	r	0.057	0.160	**0.941*** **
		Magnitude	Very Weak	Very Weak	Very Strong
Noon	PVT Mean Response Time (1)	r	1		
	Total Errors (2)	r	**0.907*** **	1	
		Magnitude	Very Strong		
	Subjective Fatigue Rating (3)	r	0.161	**0.196* **	1
		Magnitude	Very Weak	Weak	
	Subjective Sleepiness Rating (4)	r	0.153	**0.195* **	**0.930*** **
		Magnitude	Very Weak	Weak	Very Strong
Afternoon	PVT Mean Response Time (1)	r	1		
	Total Errors (2)	r	**0.848*** **	1	
		Magnitude	Very Strong		
	Subjective Fatigue Rating (3)	r	0.142	**0.214* **	1
		Magnitude	Very Weak	Weak	
	Subjective Sleepiness Rating (4)	r	0.225*	**0.302** **	**0.928*** **
		Magnitude	Weak	Weak	Very Strong
Night	PVT Mean Response Time (1)	r	1		
	Total Errors (2)	r	**0.760*** **	1	
		Magnitude	Strong		
	Subjective Fatigue Rating (3)	r	0.116	0.131	1
		Magnitude	Very Weak	Very Weak	
	Subjective Sleepiness Rating (4)	r	0.115	0.115	**0.877*** **
		Magnitude	Very Weak	Very Weak	Very Strong

N = 124; *p<0.05, **p<0.01, ***p<0.001; r = Correlation Coefficient

Research Question 2

Independent Sample T-tests were used to compare the PVT Mean Response Times and Total Errors on and off shift. The results of the Levene's test indicated that the equality of variance was assumed for all variables at any time of the day as their p-values were all above the standard significance level of 0.05 (PVT Mean Response Time p =

0.67, Total Errors p = 0.31). As indicated in Table 4-8 below, results indicate there is no significant difference in PVT Mean Response Times (t(3924) = -0.56, p = 0.58) or Total Errors (t(3924) = -1.16, p = 0.25) between days on and off shift.

Table 4-8: Results of Independent Sample T-test between On Shift and Off Shift for PVT Mean Response Times and Total Errors

Variable	**Independent Sample T-test**					
	On Shift N=1505	**Off Shift N=2421**	**Δ**	**T**	**df**	**p**
PVT Mean Response Time	459.51	455.97	-3.54	-0.56	3924	0.58
Total Errors	10.77	10.42	-3.56	-1.16	3924	0.25

N=124; Δ = mean difference; df = degree of freedom, *p< 0.05, **p< 0.01, ***p< 0.001

Research Question 3

Independent Sample T-test were used to compare the Quantity and Quality of sleep obtained on and off shift. The results of the Levene's test indicated that the equality of variance was assumed for Mean Sleep Quality as their p-value was above the standard significance level of 0.05 (p = 0.44). It was not assumed for Total Sleep Quantity as the p-value was below the standard significance level of 0.05 (p < 0.001). The results, shown in Table 4-9 below, indicate statistically significant difference of 32.02 minutes of sleep (T(*1769*) =4.31, p < 0.001). Participants slept an average of 320.35 minutes (5.3 hours) while on shift and an average of 352.38 minutes (5.9 hours) while not on shift. Mean Sleep Quality also showed a significant difference between on and off shift with quality decreasing on average 0.84% on days off (T(2155) = -2.49, p < 0.01).

Table 4-9: Results of Independent Sample T-test between On Shift and Off Shift for Total Sleep Quantity, Mean Sleep Quality, and Number of Sleep Interruptions

Variable	Independent Sample T-test					
	On Shift N=769	**Off Shift N=1388**	**Δ**	**T**	**df**	**p**
Total Sleep Quantity	320.35	352.38	**32.02*** **	4.31	1769	0.001
Mean Sleep Quality	87.64	86.8	**-0.84** **	-2.49	2155	0.01

N=124; Δ = mean difference; df = degree of freedom, *p< 0.05, **p< 0.01, ***p< 0.001

Research Hypothesis 1

For each participant, a mean value was calculated for PVT Mean Response Time, Total Errors, Subjective Fatigue Ratings and Subjective Sleepiness Ratings at each of the times of day (i.e., morning, noon, afternoon, night). The Repeated Measures ANOVA was then carried out as a parametric test to examine the mean differences of changes throughout the day (i.e., morning, noon, afternoon and night). As a rule of thumb proposed by Howell (2002) and Field (2013), Mauchly's test for the sphericity is assumed if p-value is above 0.05. If it is violated, the value of Greenhouse-Geisser should be used. If it is above 0.75, the results of Huynh-Feldt should be used. If it is less than 0.75, the results of Greenhouse-Geisser or Multivariate results should be used. As shown in Table 4.10, the results indicated that the mean values of PVT Mean Response Time and Total Errors, Subjective Fatigue Rating and Subjective Sleepiness Rating have been significantly changed from morning to night.

Table 4-10: Results of Repeated Measure ANOVA Test

Variable	Within Subject Effects & Contrasts				Partial Eta Squared	
	Mean Square	F	df	p	η^2	Magnitude
PVT Mean Response Time	25722.63**	4.294	2.726, 335.298	0.01	0.03	Small
Total Errors	65.78***	6.627	3, 369	0.001	0.05	Small
Subjective Fatigue Rating	11.998***	32.512	2.233, 274.715	0.001	0.21	Large
Subjective Sleepiness Rating	28.998***	37.753	2.212, 272.122	0.001	0.24	Large

N=124; *p< 0.05, **p< 0.01, ***p< 0.001; df = degree of freedom

Partial eta squared (η2) was used to measure the effect size of difference between variables in the ANOVA model. In interpreting the strength of the difference based on the Partial eta squared, Cohen (1988) recommendation was used. As noted by Cohen (1988), the difference between variables can be described as small if the Partial eta squared (η2) is 0.01, medium if η2 is 0.06 and large if η2 is 0.14. The following subsections discuss the results for each variable individually:

PVT Mean Response Time. The Mauchly's Test of Sphericity was significant at 0.001 level, which violates the assumption of Sphericity. The value of Greenhouse-Geisser was 0.887, above the threshold of 0.75. Therefore, the correction method of Huynh-Feldt was used per recommended by Howell (2002) and Field (2013). The results of Huynh-Feldt were significant at 0.01 level, indicating the mean value of PVT Mean Response Time has been significantly changed through the four times of the day (i.e., morning, noon, afternoon and night). The results also indicated that the magnitude of changes throughout the day is small ($\eta^2 < 0.06$); $F(2.726, 335.298) = 4.294$, $p < 0.01$, $\eta^2 = 0.034$.

Total Errors. The Mauchly's Test of Sphericity was 0.115, above the standard significant level of 0.05. Therefore, the sphericity assumption is met for Total Errors. The results of repeated measure ANOVA were significant at 0.001 level, indicating the mean value of Total Errors has been significantly changed through the four times of the day (i.e., morning, noon, afternoon and night). The results also indicated that the magnitude of changes throughout the day is small ($\eta^2 < 0.06$); $F(3, 369) = 6.627$, $p < 0.001$, $\eta^2 = 0.051$.

Subjective Fatigue Rating. The Mauchly's Test of Sphericity was significant at 0.001 level, which violated the assumption of Sphericity. The value of Greenhouse-Geisser was 0.774, lower than the threshold of 0.75. Therefore, the correction method of Greenhouse-Geisser was used per recommended by Howell (2002) and Field (2013). The results of Greenhouse-Geisser were significant at 0.001 level, indicating the mean value of Subjective Fatigue Rating has been significantly changed through the four times of the day (i.e., morning, noon, afternoon and night). The results also indicated that the magnitude of changes throughout the day is small ($\eta^2 > 0.14$); $F(2.233, 274.715) = 35.512$, $p < 0.001$, $\eta^2 = 0.209$.

Subjective Sleepiness Rating. The Mauchly's Test of Sphericity was significant at 0.001 level, which violated the assumption of Sphericity. The value of Greenhouse-Geisser was 0.37, lower than the threshold of 0.75. Therefore, the correction method of Greenhouse-Geisser was used per recommended by Howell (2002) and Field (2013). The results of Greenhouse-Geisser were significant at 0.001 level, indicating the mean value of Subjective Sleepiness Rating has been significantly changed through the four times of the day (i.e., morning, noon, afternoon and night). The results also indicated that the magnitude of changes throughout the day is small ($\eta^2 > 0.14$); $F(2.212, 272.122) = 37.753$, $p < 0.001$, $\eta^2 = 0.234$.

In addition to determining the mean differences of variables between the four times of the day, post hoc testing determines which variable means differ and where the differences may lie between each paired time of day (i.e., Morning vs Noon, Morning vs Afternoon, Morning vs Night, Noon vs Afternoon, Noon vs Night, Afternoon vs Night). The results, shown in Table 4-11, indicate the mean values of PVT Mean Response Time, Total Errors, Subjective Fatigue Rating and Subjective Sleepiness Rating have been significantly changed at least between two times of a day. The following subsections discuss the results for each variable individually:

Table 4-11: Results of Post-hoc Test for Pairwise Comparison between the Four Times of the Day

Variable	Mean Value								
	Morning	**Noon**	**Afternoon**	**Night**	**Difference (Δ)**	**SE**	**p**	**LL95%CI**	**UL95 %CI**
PVT Mean Response Time	433.727	445.318			-11.592	8.863	1.000	-35.360	12.176
	433.727		453.562		-19.836	8.941	0.170	-43.811	4.140
	433.727			466.320	-32.593**	8.557	0.001	-55.539	-9.648
		445.318	453.562		-8.244	8.608	1.000	-31.328	14.840
		445.318		466.320	-21.002	9.710	0.195	-47.040	5.037
			453.562	466.320	-12.758	11.255	1.000	-42.938	17.422
Total Errors	9.713	10.298			-0.585	0.392	0.830	-1.636	0.466
	9.713		10.672		-0.959	0.401	0.110	-2.034	0.116
	9.713			11.452	-1.739***	0.383	0.000	-2.765	-0.713
		10.298	10.672		-0.374	0.385	1.000	-1.407	0.659
		10.298		11.452	-1.154*	0.382	0.019	-2.179	-0.129
			10.672	11.452	-0.780	0.453	0.525	-0.435	1.995
Subjective Fatigue Rating	3.293	2.733			0.560***	0.064	0.000	0.389	0.731
	3.293		2.811		0.482***	0.070	0.000	0.295	0.670
	3.293			3.083	0.210	0.081	0.065	-0.007	0.428
		2.733	2.811		-0.077	0.050	0.758	-0.212	0.057
		2.733		3.083	-0.350***	0.066	0.000	-0.525	-0.174
			2.811	3.083	-0.272***	0.045	0.000	-0.392	-0.153
	4.061	3.158			0.903***	0.090	0.000	0.662	1.144

Subjective Sleepiness Rating	4.061		3.276		0.785***	0.099	0.000	0.520	1.050
	4.061			3.716	0.345*	0.127	0.046	0.003	0.686
		3.158	3.276		-0.118	0.073	0.640	-0.313	0.077
		3.158		3.716	-0.558***	0.097	0.000	-0.818	-0.299
			3.276	3.716	-0.440***	0.078	0.000	-0.650	-0.230

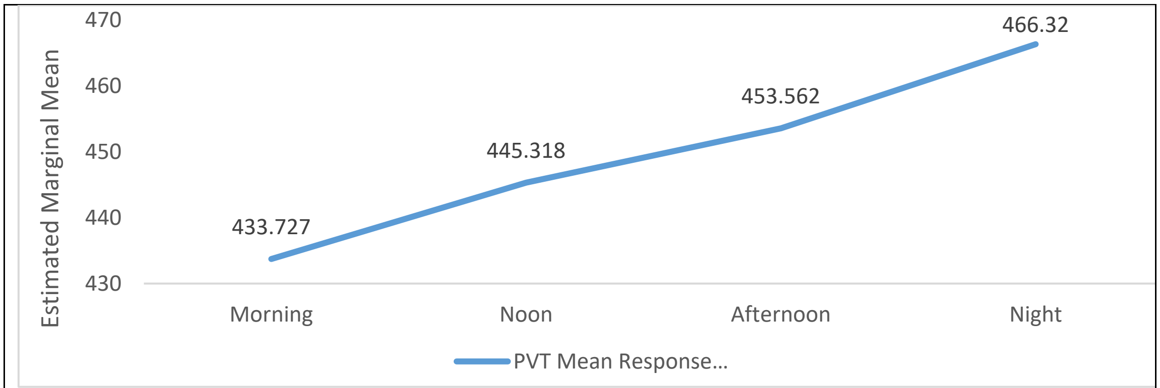
N=124; SE = standard Error; *p< 0.05, **p< 0.01, ***p< 0.001; df = degree of freedom

PVT Mean Response Time. The descriptive results indicated the mean value of PVT Mean Response Time gradually increased from morning to night. However, the results of post hoc test indicated that only the mean value of PVT Mean Response Time at night (466.320) was significantly higher than the morning (433.727) because of having p-value significant at 0.01 level; Δ = -32.593, $p < 0.01$, the 95% confidence interval (CI) does not include 0; CI is -0.55.539 and -9.648. There is no significant difference in the mean value of PVT Mean Response Time at other pairwise comparison of the four times of day because of having p-values above the standard significant level of 0.05.

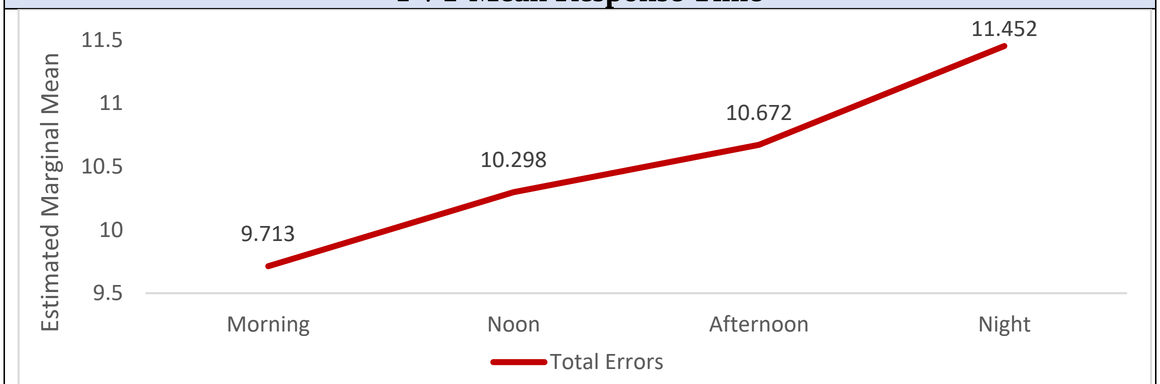
Total Errors. The descriptive results indicated the mean value of Total Errors gradually increased from morning to night. The results of post hoc test indicated that the mean value of Total Errors at night (11.452) was significantly higher than the morning (9.713); Δ = -1.739, $p < 0.001$, the 95% confidence interval (CI) does not include 0; CI is -2.765 and -0.713. The results also indicated that the mean value of Total Errors at night (11.452) was significantly higher than the noon (10.298); Δ = -0.129, $p < 0.05$, the 95% confidence interval (CI) does not include 0; CI is -2.179 and -0.129. There is no significant differences in the mean value of Total Errors at other pairwise comparison of the four times of day because of having p-values above the standard significant level of 0.05.

Subjective Fatigue Rating. The descriptive results indicated the mean value of Subjective Fatigue Rating was highest at the morning. Then it significantly decreased at noon followed by a gradual increase from noon to night. The results of post hoc test indicated that the mean value of Subjective Fatigue Rating at morning (3.293) was significantly higher than the noon (2.733) ($\Delta = 0.560$, $p < 0.001$, 95%CI is 0.389 and 0.731) and afternoon (2.811) ($\Delta = 0.482$, $p < 0.001$, 95%CI is 0.295 and 0.670). The results also indicate the mean value of Subjective Fatigue Rating at night (3.083) was significantly higher than noon (2.733) ($\Delta = -0.350$, $p < 0.001$, 95% CI is -0.525 and 0.174) afternoon (2.811) ($\Delta = -0.272$, $p < 0.001$, 95% CI is -0.392 and -0.153).

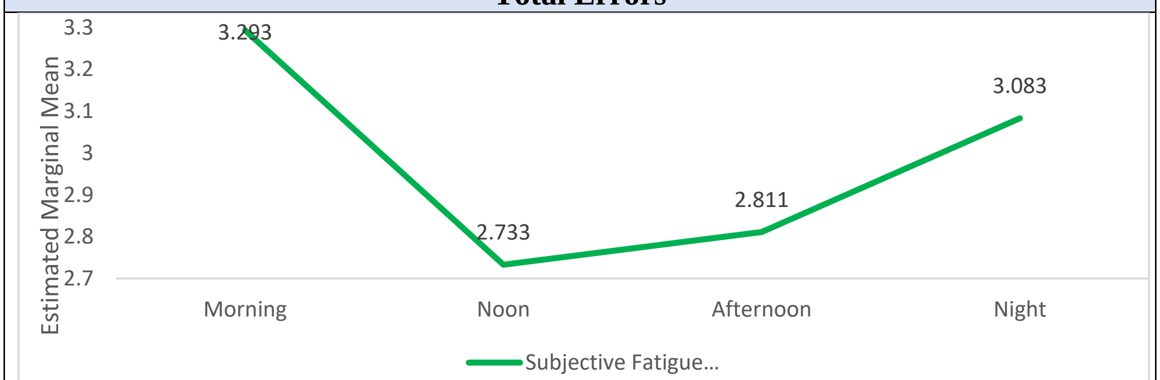
Subjective Sleepiness Rating. The descriptive results indicate the mean value of Subjective Sleepiness Rating was highest at the morning. Then it significantly decreased at noon, followed by a gradual increase from noon to night. The results of post hoc test indicated that the mean value of Subjective Sleepiness Rating at **morning** (4.061) was significantly higher than noon (3.158) ($\Delta = 0.903$, $p < 0.001$, 95%CI is 0.662 and 1.144), afternoon (3.276) ($\Delta = 0.785$, $p < 0.001$, 95%CI is 0.520 and 1.050) and night (3.716) ($\Delta = 0.345$, $p < 0.05$, 95%CI is 0.003 and 0.686). The results also indicated that the mean value of Subjective Sleepiness Rating at **night** (3.716) was significantly higher than noon (3.158) ($\Delta = -0.558$, $p < 0.001$, 95% CI is -0.818 and -0.299) and afternoon (3.276) ($\Delta = -0.440$, $p < 0.001$, 95% CI is -0.650 and -0.230).



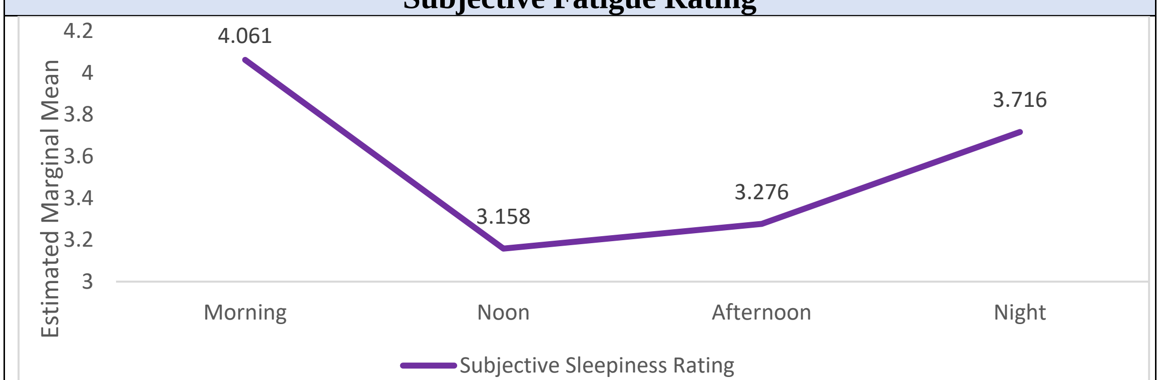
PVT Mean Response Time



Total Errors



Subjective Fatigue Rating



Subjective Sleepiness Rating

Figure 4-1: Line Chart of Variables' Mean Differences through the Four Times of a Day

As shown, PVT Mean Response Time and Total Errors are gradually increased from morning thru night. But Subjective Fatigue Rating and Subjective Sleepiness Rating show a decrease from morning thru noon and then increased from noon through night. Participants reported less fatigue and sleepiness, despite continued decreases in cognitive performance.

Research Hypothesis 2

Pearson Correlation was used to evaluate the relationships amongst between Age, BMI, Resting Heart Rate, Total Sleep Quantity, Mean Sleep Quality, Workload and On Shift. As shown in Table 4-12, the results indicated Age is significantly and positively, but weakly correlation with BMI ($r = 0.240$, $p < 0.01$, weak) and Resting Heart Rate ($r = 0.409$, $p < 0.001$, moderate). BMI was also in significant positive, but weak correlation

Table 4-12: Results of Pearson Correlation between Age, BMI, Resting Heart Rate, Total Sleep Quantity, Mean Sleep Quality, and Workload

Day Time	Variable		(1)	(2)	(3)	(4)	(5)	(6)
Overall	Age (1)	r	**1**					
	BMI (2)	r Magnitude	**0.240**** Weak	**1**				
	Resting Heart Rate (3)	r Magnitude	**0.409***** Moderate	**0.282**** Weak	**1**			
	Total Sleep Quantity (4)	r Magnitude	-0.135 Very Weak	**-0.237**** Weak	-0.120 Very Weak	**1**		
	Mean Sleep Quality (5)	r Magnitude	0.042 Very Weak	0.093 Very Weak	-0.130 Very Weak	0.020 Very Weak	1	
	Workload (6)	r Magnitude	-0.088 Very Weak	0.015 Very	**-0406***** Moderate	-0.150 Very	0.045 Very Weak	1
	On Shift (7)	r Magnitude	-0.017 Very Weak	0.080 Very	-0.031 Very Weak	-0.153 Very	0.007 Very Weak	-0.010 Very Weak

N = 124; *p<0.05, **p<0.01, ***p<0.001; r = Correlation Coefficient with Resting Heart Rate (r = 0.282, p < 0.01, weak). BMI was in significant negative correlation with Total Sleep Quantity (r = -0.237, p < 0.01, weak). Heart Rate is also significantly, negatively, and moderately correlated with Workload; r = -0.406, p < 0.001.

Correlations were also evaluated between these variables and PVT Mean Response Times, PVT Total Errors, Subjective Fatigue Ratings, and Subjective Sleepiness Ratings at the different times of day (i.e., morning, noon, afternoon, night). Table 4-13 indicates BMI, Resting Heart Rate, Total Sleep Quantity, Mean Sleep Quality,

Table 4-13: Results of Pearson Correlation between Continuous Variables

Day Time	Variable	Age	BMI	Resting Heart Rate	Total Sleep Quantity	Mean Sleep Quality	Workload
Morning	PVT Mean Response Time	-0.122	-0.009	-0.023	-0.072	0.067	-0.014
	Total Errors	-0.168	-0.037	0.024	-0.082	0.034	-0.031
	Subjective Fatigue Rating	-0.152	-0.047	0.066	-0.007	-0.064	0.062
	Subjective Sleepiness	-0.153	-0.083	0.07	-0.036	-0.084	0.083
Noon	PVT Mean Response Time	-0.086	-0.02	0.12	-0.121	-0.053	-0.079
	Total Errors	-0.057	-0.02	0.135	-0.137	0.008	-0.064
	Subjective Fatigue Rating	**-.190***	-0.103	-0.023	-0.014	-0.157	0.065
	Subjective Sleepiness	-0.165	-0.113	0.013	-0.074	-0.174	0.023
Afternoon	PVT Mean Response Time	-0.078	0.07	-0.004	-0.046	-0.016	0.035
	Total Errors	-0.128	-0.013	0.024	-0.101	-0.008	0.008
	Subjective Fatigue Rating	-0.076	-0.023	0.007	0.036	-0.023	-0.021
	Subjective Sleepiness	-0.115	-0.087	0.012	0.001	-0.036	-0.013
Night	PVT Mean Response Time	-0.102	-0.01	0.029	-0.156	-0.016	0.11
	Total Errors	-0.08	-0.032	0.113	-0.144	0.088	0.006
	Subjective Fatigue Rating	-0.041	0.02	0.015	0.008	0.022	0.105
	Subjective Sleepiness	-0.045	-0.054	0.012	-0.016	0.022	0.044

Note: the magnitude of all correlations are "Very weak"; N = 124; *p<0.05, **p<0.01, ***p<0.001; r = Correlation Coefficient;

and Workload were not significantly correlated with PVT Mean Response Time, Total Errors, Subjective Fatigue Rating and Subjective Sleepiness Rating. The only significant correlation indicated was Age and Subjective Fatigue Rating at noon, which are significantly and negatively, but very weakly correlated with each other; r = -0.190, $p < 0.05$.

Research Hypothesis 3

An Independent Sample T-test was used to examine the mean differences between the groups with different shift structures (24 Hr. and 48-Hr.) The results of the Levene's test indicated that the equality of variance was assumed for all variables at any time of the day as their p-values were all above the standard significance level of 0.05. Morning - PVT Mean Response Time p = 0.85, Total Errors p = 0.98, Subjective Fatigue Rating p = 0.57, Subjective Sleepiness Rating p = 0.57; Noon - PVT Mean Response Time p = 0.59, Total Errors p = 0.68, Subjective Fatigue Rating p = 0.25, Subjective Sleepiness Rating p = 0.55; Afternoon - PVT Mean Response Time p = 0.07, Total Errors p = 0.15, Subjective Fatigue Rating p = 0.17, Subjective Sleepiness Rating p = 0.21; Night - PVT Mean Response Time p = 0.09, Total Errors p = 0.72, Subjective Fatigue Rating p = 0.14, Subjective Sleepiness Rating p = 0.08 Total . As shown in Table 4-14, the results indicate the mean values of variables are not significantly changed between the shift structure groups at any time of day.

Table 4-14: Independent Sample T-test for the Groups of Shift Structure

Day Time	Variable	Independent Sample T-test					
		24 hours (n=96)	48 hours (n=28)	Δ	T	df	p
Morning	PVT Mean Response Time	435.822	426.543	9.279	0.382	122	0.703
	Total Errors	9.704	9.745	-0.041	-0.029	122	0.977
	Subjective Fatigue Rating	3.325	3.185	0.14	0.691	122	0.491
	Subjective Sleepiness Rating	4.108	3.900	0.208	0.735	122	0.464

Noon	PVT Mean Response Time	444.895	446.769	-1.874	-0.074	122	0.941
	Total Errors	10.343	10.145	0.198	0.127	122	0.899
	Subjective Fatigue Rating	2.734	2.732	0.002	0.01	122	0.992
	Subjective Sleepiness Rating	3.120	3.287	-0.167	-0.713	122	0.477
Afternoon	PVT Mean Response Time	462.969	421.310	41.659	1.482	122	0.141
	Total Errors	10.974	9.636	1.338	0.9	122	0.37
	Subjective Fatigue Rating	2.839	2.714	0.125	0.677	122	0.5
	Subjective Sleepiness Rating	3.323	3.115	0.208	0.823	122	0.412
Night	PVT Mean Response Time	470.871	450.717	20.154	0.635	122	0.527
	Total Errors	11.203	12.307	-1.104	-0.675	122	0.501
	Subjective Fatigue Rating	3.128	2.930	0.198	1.045	122	0.298
	Subjective Sleepiness Rating	3.776	3.510	0.266	0.998	122	0.32

N=124; Δ = mean difference; df = degree of freedom

Research Hypothesis 4

An Independent Sample T-test was used to evaluate the differences between groups with different years of experience in the fire service. The comparison is between those with 0-10 years and those with 11-20 years of experience. The group with 21-35 years of experience was excluded from comparison because it was too small for valid comparison. The equality of variance was assumed for all variables at any time of the day as their p-values were all above the standard significance level of 0.05 (Morning – PVT Mean Response Time p = 0.56, Total Errors p= 0.90, Subjective Fatigue Rating p = 0.78, Subjective Sleepiness Rating p = 0.30; Noon – PVT Mean Response Time p = 0.23, Total Errors p= 0.64, Subjective Fatigue Rating p = 0.06, Subjective Sleepiness Rating p = 0.09; Afternoon – PVT Mean Response Time p = 0.42, Total Errors p= 0.39, Subjective Fatigue Rating p = 0.34, Subjective Sleepiness Rating p = 0.76; Night – PVT Mean Response Time p = 0.86, Total Errors p= 0.98, Subjective Fatigue Rating p = 0.51, Subjective Sleepiness Rating p = 0.49). As shown in Table 4-15, the results of the

Independent Sample T-test indicate the mean value of Subjective Fatigue Ratings for 11 – 20 years of experience in fire service (M = 3.370) is significantly higher than those with 0 – 10 years in fire service (M = 2.959) at night; Mean difference (Δ) = -0.411, T(106) = -2.387, $p < 0.05$. The results also indicated that the mean value of Subjective Sleepiness Rating for 11 – 20 years of experience in fire service (M = 4.089) is significantly higher than those with 0 – 10 years in fire service (M = 3.553) at night; Mean difference (Δ) = -0.536, T(106) = -2.167, $p < 0.05$. No significant differences for PVT Mean Response Times or Total Errors were observed at any time of day.

Table 4-15: Results of Independent Sample T-test for the Groups with Different Years of Service

Day Time	Variable	Independent Sample T-test					
		0-10 years (n=63)	11 – 20 years (n=43)	Δ	T	df	p
Morning	PVT Mean Response Time	435.048	449.795	-14.747	-0.761	104	0.449
	Total Errors	9.843	9.891	-0.048	-0.038	104	0.97
	Subjective Fatigue Rating	3.293	3.430	-0.137	-0.741	106	0.461
	Subjective Sleepiness Rating	4.062	4.209	-0.147	-0.568	106	0.571
Noon	PVT Mean Response Time	435.077	465.761	-30.684	-1.338	106	0.184
	Total Errors	9.820	10.859	-1.039	-0.737	106	0.463
	Subjective Fatigue Rating	2.755	2.842	-0.087	-0.524	106	0.601
	Subjective Sleepiness Rating	3.174	3.340	-0.166	-0.76	106	0.449
Afternoon	PVT Mean Response Time	454.725	462.913	-8.188	-0.326	105	0.745
	Total Errors	10.842	10.789	0.052	0.038	105	0.97
	Subjective Fatigue Rating	2.757	3.016	-0.259	-1.504	106	0.136
	Subjective Sleepiness Rating	3.228	3.551	-0.323	-1.352	106	0.179
Night	PVT Mean Response Time	465.926	490.547	-24.622	-0.897	104	0.372
	Total Errors	11.313	12.261	-0.948	-0.623	104	0.535
	Subjective Fatigue Rating	2.959	3.370	**-0.411***	-2.387	106	0.019
	Subjective Sleepiness Rating	3.553	4.089	**-0.536***	-2.167	106	0.032

N=124; Δ = mean difference; * $P < 0.05$; df = degree of freedom

Research Hypothesis 5

Linear regression across 5% SAFTE prediction bins revealed significant but weak correlations between SAFTE Predicted Effectiveness and PVT Actual Effectiveness ($R2 = 0.63$, $F(1, 6) = 10.17$, $p < 0.019$). As shown in Figure 4-2, results indicate SAFTE Predicted Effectiveness and Actual Effectiveness were dissimilar in that Actual Effectiveness scores were more evenly distributed than Predicted Effectiveness scores.

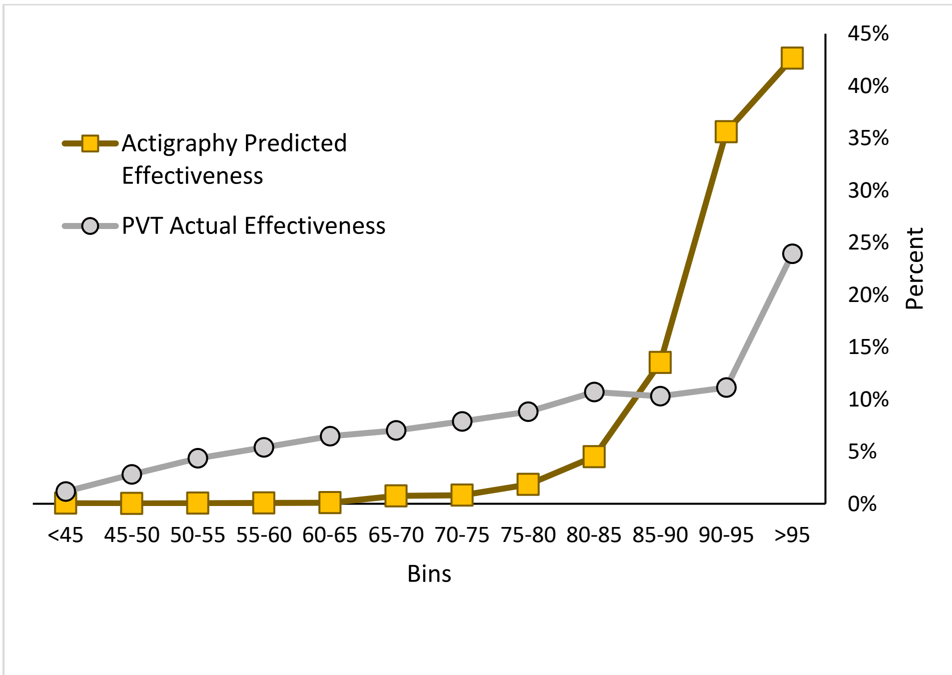


Figure 4-2: Predicted Effectiveness vs. Actual Effectiveness Distributions Across 5% Bins

Agreement between Predicted Effectiveness and PVT Actual Effectiveness scores were additionally visualized using Bland–Altman plots (Bland and Altman 1986). Limits of agreement were computed (mean difference ± 1.96 SD) to indicate the range in which the differences between the two measures would occur with 95% probability. As shown in Figure 4-3, the polynomial best fit curves indicate proportional error.

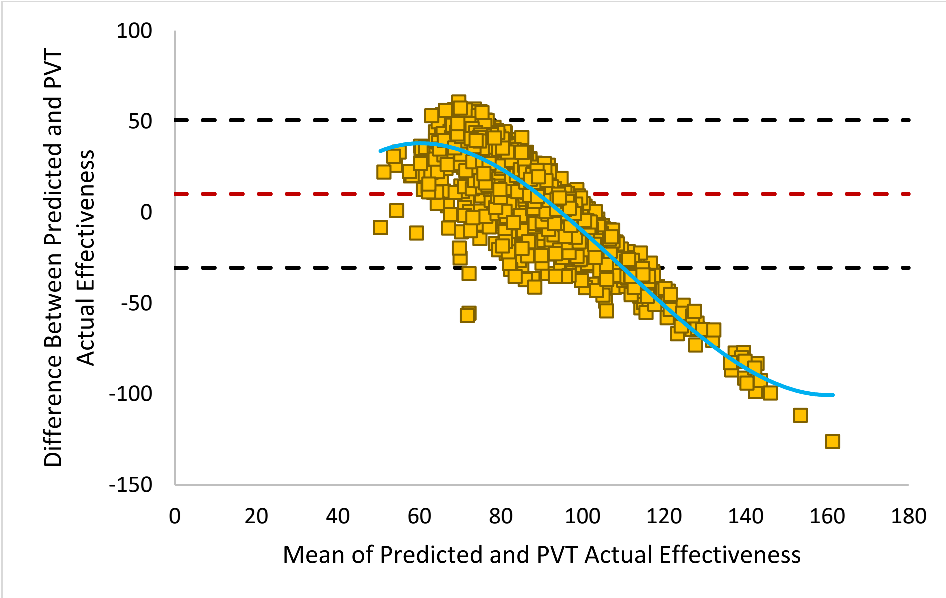


Figure 4-3: Bland–Altman plot of the difference (y-axis) between Actigraphy Predicted Effectiveness and PVT Actual Effectiveness versus the mean of the two measurements (x-axis). Bias is represented by the dashed red line (- -). Upper and lower limits of agreement (LOAs) are represented by the black dashed lines (- -). Upper and lower LOAs represent two standard deviations from the bias. Narrower LOAs indicate relatively less variability than wider LOAs. The solid blue curve (—) represents the best fit of data.

CHAPTER V

DISCUSSION

Overview

Limited studies have been conducted to evaluate the impact of fatigue on firefighters' cognitive function. Most of these studies took place within laboratory or simulated work environments (Armstrong et al., 2013; Greenlee et al., 2014; Kujawski et al., 2018; Morley et al., 2012). Two were conducted within the work environment, but the working conditions were not consistent with the majority of fire departments within the US (Paley & Tepas, 1994; Takeyama et al., 2005). These studies aid in understanding firefighter fatigue and the impact it has on their cognitive performance. However, the results of these studies are not generalizable because they are all conducted in settings which are not representative of the combined physiological and psychological strain that a firefighter is exposed to repeatedly during the course of a 24 or 48-hour shift in the majority of US fire departments. This dissertation built on previous work by evaluating the cognitive function of firefighters within their work environment, under normal working conditions, which are representative of the majority of fire departments within the US (everyone is alerted for every emergency call, throughout the shift, regardless of whether they need to respond or not).

Demographic Variables

Fatigue may be exacerbated by psychological, physiological, socioeconomic, and environmental factors (Sedighi Maman et al., 2017; Yung, Bigelow, Hastings, & Wells, 2014). Demographic factors such as age, gender, and ethnicity are often evaluated to look for these types of differences in sample populations. In previous studies age, gender, and ethnicity have been found to be relevant variables (Di Milia et al., 2011; Lombardi, Folkard, Willetts, & Smith, 2010; Lu, Sesek, Megahed, & Cavuoto, 2017). In this study data was collected on all of these factors, however, gender was not analyzed because the sample did not include enough female participants for valid test results. Ethnicity also had to be excluded for comparison due to insufficient representation of minorities. Age was not significantly correlated with PVT mean response times or total number of errors. It was significantly and positively correlated with BMI and Resting Heart Rate, meaning as firefighters get older, their BMI and Resting Heart Rates also increase. This is consistent with studies in other fields.

The other two demographic variables that were evaluated in this study were shift structure (24 or 48-hour shifts) and time in service. These factors have not be evaluated in previous studies. They were included in this study because there was interest from fire departments in understanding whether or not there were differences resulting from these factors. Shift structure was of interest because some departments were considering a change from a 24-hour shift structure to a 48-hour shift structure, but resources were not available to justify the decision. The years of experience were of interest because there was speculation that with increased years of experience firefighters become better able to cope with exposure to fatigue.

There was no significant difference observed between shift structures. It was anticipated there would be a significant difference due to time-on-task differences reported in previous studies. Folkard and Lombardi (2006) found the risk of injury begins to increase after eight hours of work, this amplification of risk increases by 13% after 10 hours on the job, and increases by 30% after 12 hours on the job. Dawson and Reid (1997), found that a person may be so fatigued after 16 hours that he/she may no longer be capable of performing at the desired level. Furthermore, with medical residents working 24-to-30-hour shifts, alertness and performance dropped dramatically after 16 to 18 hours on the job (Lockley et al., 2007).

Firefighters are most often not required to sustain wakefulness for their entire shift (24 or 48-hours); however, they are called upon to respond at all hours of the day and night. This study used Independent Sample T-tests to compare the mean value of the cognitive performance variables (response time and total errors) and subjective ratings (sleepiness and fatigue) between those working 24 and 48 hours. Differences may not have been observed between these shift structures because the amount of time actually worked was similar. Many of the firefighters working on the 24-hour shift structure reported workings several days in a row (overtime), which resulted in them working approximately the same timeframe as those in the 48-hour shift structure. The number of those in this study who did not work overtime was too small for valid statistical comparison. Future research should obtain a sample from those working the 24-hour shift structure which do not include overtime work for more accurate comparison of the shift structures.

The only significant differences observed for groups with different years of experience was at night, when those with 11-20 years of service rate their sleepiness and fatigue higher than those with 0-10 years of experience. This variable was of interest to some participating fire departments because of speculation that firefighters are better able to cope with fatigue with increased experience. The results do not support that speculation. There was no significant difference observed between the cognitive performance variables (response time and total errors) between the groups with different years of experience.

Biometrics Variables

Methods that have been identified in previous studies as effective measurements of fatigue include heart rate (Cavuoto & Megahed, 2017; Yung et al., 2014), body temperature (Knauth, Rutenfranz, Herrmann, & Poppel, 1978; Morley et al., 2012; Rosa & Colligan, 1988), and Body Mass Index (BMI) (Brake & Bates, 2001; Caruso, Hitchcock, Dick, Russo, & Schmit, 2004; Kales, Polyhronopoulos, Aldrich, Leitao, & Christiani, 1999). For comparison purposes, this same data was collected in this study. Body temperature was excluded from analysis due to insufficient data points for valid comparison.

Resting heart rate had significant, negative and moderate correlation with workload. This indicates as resting heart rate increased, workload decreased. The workload variable in this study was calculated as a percent of the maximum heart rate, therefore the higher an individual's resting heart rate, the less the heart rate has to increase to get to the maximum workload. Those who have higher resting heart rates are already working at a higher workload, so less of an increase is observed as participants report increased heart rates at later points in the day. If a participant reports a heart rate lower than the resting heart rate they had initially reported, then it would appear the workload is decreasing. Resting heart rates were obtained at the end of the initial meeting, which was approximately 10:00 for most of the participants and was an on-shift day for all of them. It is possible that the resting heart rate obtained at this time of day, on a work day, is higher than if it had been obtained prior to any activity and on a day off. Correlation analysis, presented in Table 4-12, however, did not indicate there was a significant correlation between workload days on/off shift. Further research to compare workload on and off shift is recommended.

It is no surprise that age, BMI, resting heart rate, and workload are correlated with each other. It is surprising, however, that no significant correlations were found between these factors and PVT mean response times, PVT total errors, subjective fatigue ratings and subjective sleepiness ratings, because they have been found to be significant in many previous studies. The difference between previous studies and the current study may be due to chronic fatigue. In previous studies, the participants were provided a rest period of at least eight hours, some longer, prior to the beginning of the study. Participants in this study were not provided a rest period prior to participation. It is assumed their sleep patterns during the study are representative of their sleep patterns prior to the study. During this study participants slept an average of 5.3 hours while on shift and an average of 5.9 hours while not on shift. This is well below the recommended 8 hours. Roehrs and collegues' (2003) research indicated that losing two hours of sleep from the recommended eight hours could results in performance equivalent to a person who has drank two to three beers. It could be possible that little correlation is observed because mean values were used for this analysis. It is recommended that a larger sample be obtained and multiple linear regression be used to analyze the effect that each of these biometric variables has on the PVT mean response times, PVT total errors, subjective fatigue ratings and subjective sleepiness ratings.

Fatigue (Cognitive Performance Impairment)

The Psychomotor Vigilance Task is one of the most frequently used measures of cognitive performance (Thomas J. Balkin & Wesensten, 2011)(Thomann et al., 2014). The most common variables used from the PVT in research is response times and total errors (Cavuoto & Megahed, 2017; Morley et al., 2012; Powell & Copping, 2016). Results of research have consistently shown the PVT is sensitive to fatigue and sleep loss, which result in changes to reaction times and errors. However, there is some discrepancy in the types of changes observed. Most researchers report findings of increased reaction times (takes longer to respond) and increased errors (missed signals or responding in the absence of stimuli) by test subjects who are fatigued (Gerdes, Kahol, Smith, Leyba, & Ferrara, 2008; Lombardi, Folkard, Willetts, & Smith, 2010; Morley et al., 2012; Scott, Rogers, Hwang, & Zhang, 2006; Williamson et al., 2011). Conversely, some researchers have reported decreased reaction times and increased errors by test subjects (Fan & Smith, 2017; Grego et al., 2005; Kujawski et al., 2018). It is interesting to note, that all three of these studies were applying workload increases (physical stress) without increasing mental stress. This may imply a stronger connection between cognitive workload and response time. Meaning when the mind is stressed, it may take longer to process signals. In the present study PVT Mean Response Time and Total Errors were significantly and positively correlated at all times of the day. As the day went on, participants took longer to respond to the same signals and were less accurate in their responses.

Research has shown that people are typically poor at recognizing their own fatigue (Horne & Baulk, 2004; Kaplan et al., 2007; Lockley et al., 2007; Scott et al., 2007). The findings of this study were consistent with previous research. Few correlations were observed, those that were observed were weak, and they were inconsistent at different times of the day. The participants of the current study, reported the highest ratings of fatigue and sleepiness in the morning. These ratings were significantly and largely decreased from morning to noon, despite continued decline of cognitive performance during this same time period. PVT Total Errors were significantly and positively, but weakly correlated with Subjective Fatigue Rating only at noon and afternoon. PVT results and subjective ratings were not correlated in the morning or night. The lack of correlations between subjective and objective measures throughout the day may indicate that participants were not able to accurate identify their fatigue, as previous researchers have indicated.

Alternatively, this is likely a time-since-waking effect. The large, significant decrease in fatigue and sleepiness ratings were observed between morning and noon. Participants may be reporting the highest levels of sleepiness and fatigue in the morning and reporting they feel better at noon due to sleep inertia, sometimes referred to as grogginess. Sleep inertia is strongest immediately after waking, but the effects may last up to several hours (Jewett et al., 1999; S. W. Lockley et al., 2007). The morning journal entries were completed around 08:00.

This finding may also be the result of a time-of-day effect. This type of effect occurs due to the body's circadian rhythms. The circadian rhythm, in turn, affects hormone production. Just prior to the time period when participants were completing this journal entry (08:00), the body was cycling between melatonin (sleep hormone) and cortisol (wake-up hormone). There is some variation in individuals, but on average, the body begins releasing cortisol into the systems around 06:00-07:00 and reaches a peak around 09:00-10:00. (Fahey & Zee, 2020). Even without sleep deprivation, cognitive performance has been shown to be affected by the body's circadian rhythms (Mountain et al., 2007). This result is consistent with findings from the National Safety Council's research on fatigue, which reported the average person was most alert at 10:00 and alertness diminished throughout the day (National Safety Council, 2019a).

Subjective Fatigue Ratings and Subjective Sleepiness Ratings were significantly, positively, and very strongly correlated at all times of the day. This may indicate the participants were not able to differentiate between sleepiness and fatigue. This difficulty could be because participants did not understand the difference between the two scales. They were instructed to increase their fatigue score when they felt an increase in difficulty thinking or making decisions (indicating a need to stop activities and rest) and increase sleepiness score if they felt difficulty staying awake (indicating need for sleep). Alternatively, due to chronic sleep deprivation observed during this study, they may continually be experiencing both at levels that makes it difficult to differentiate causation (need for sleep, or need for physical and mental rest).Previous research has shown fatigue to be influenced by quantity and quality of sleep (Billings & Focht, 2016; Conner et al., 2002; Cummings et al., 2001; Dawson et al., 2011; Lockley et al., 2004; Patterson et al., 2010; Wadsworth et al., 2006), time of day (Folkard, 1997; Mountain et al., 2007; Williamson et al., 2011), time on task (Bendak & Rashid, 2020; Cavuoto & Megahed, 2017; Harrington, 2001), workload (Fan & Smith, 2017; Grego et al., 2005; Kujawski et al., 2018; Morley et al., 2012), time since waking (Jewett et al., 1999; S. W. Lockley et al., 2007; Mountain et al., 2007; Wertz et al., 2006; Williamson et al., 2011), and start time (Akerstedt & Folkard, 1995; Billings & Focht, 2016; Folkard, 1997; Harrington, 2001; Williamson et al., 2011; Zulley, 1990). Many of these same factors were evaluated in this study. The start time for all fire departments that participated in this study were the same, so comparison was not possible. Due to the data cleansing processes that occurred prior to analysis, the sample size was not large enough to obtain valid results from multiple linear regression of the remaining variables to analyze which were the strongest predictors of cognitive performance. Correlation analysis did not show a relationship between sleep quantity or quality, workload and PVT response times or total errors. A larger sample size and further research is needed to determine which factors are the strongest predictors of cognitive performance.

No previous studies were found that evaluated recovery time for firefighters working 24 or 48-hour shifts. The current study sought to determine if recovery was occurring during days off for either shift structure. The comparison of PVT Mean Response Times showed no significant difference between days on (M= 460ms) and off shift (M=456ms). Total Errors also showed no significant difference between on shift (M=10.8) and off shift day (M=10.5). The mean response times are within the range that is considered normal (up to 500ms), nevertheless they are very close to the cutoff point (Ackerman, 2011). No studies were found that indicated what is considered a normal range for number of errors, they simply compare the number of errors at different times during the study to show increases or decreases.

It is also important to note, that while the mean was within normal range, at all times of the day an average of 25% (Range 22-27%) of the participants had mean response times greater than 500ms. This indicates approximately 1 in 4 of the participants was performing at a level indicative of impairment at all times of the day and this does not improve on days off. Since there is no significant difference between cognitive function variables on and off shift, it is unlikely that simply adding more days off would alter these results. Because these measures are extremely sensitive to sleep loss, further research into sleep hygiene factors affecting the fire service would likely be beneficial.

Further research into the use of biomathematical models may also be beneficial. These types of models have not been used previously within the fire service. The model tested here, SAFTE, showed significant and moderate correlation between predicted and actual effectiveness. With additional research and refinement, the model can be made more accurate.

This study indicates firefighters may be chronically sleep deprived and at increased risk of injury and illness throughout the day, as well as cumulative health issues. These results are consistent with previous research, which has consistently found that firefighters are sleep deprived and the quality of their sleep is reduced by frequent interruptions both on and off shift (Billings & Focht, 2016; Carey, Al-Zaiti, Dean, Sessanna, & Finnell, 2011; Lusa, Hakkanen, Luukkonen, & Viikari-Juntura, 2002; Mehrdad, Haghighi, & Esfahani, 2013; Patterson et al., 2010).

The American Academy of Sleep Medicine and Sleep Research Society recommends adults between the ages of 18-60 get 7-8 hours of sleep per night (Watson et al., 2015). During the course of this study, participants got an average of 5-6 hours of sleep per night, with an average of 2 interruptions (Range 0-7). This is well below the recommended amount of sleep. Sleep loss from one night can be made up with sleep the subsequent day, however sleep loss on consecutive days for a week or more, may no longer be compensable (Knauth, 1996). Accumulation of sleep debt results in fatigue, which has direct impact on cognitive performance. This study revealed that impact on firefighters working both 24 and 48-hour shifts. Mean PVT response times between 150 – 500 milliseconds(ms) are considered alert responses while responses greater than 500 ms are considered impaired (Ackerman, 2011). Mean PVT response times for this study began at 434 ms in the morning (approximately 8am) and gradually increased throughout the day to 466 ms in the evening (approximately 8pm). Approximately 22% of participants began work each day with their cognitive performance already impaired at a level equivalent to alcohol intoxication (Howard et al., 2007). Furthermore, by the afternoon (4pm) more than a quarter of firefighters on duty (27%) were performing at the same level of cognitive impairment as someone who is intoxicated. Firefighters would not be allowed to work under the influence of alcohol, but they are working under the influence of fatigue which has similar effects on performance.

Implications of Research

Research directly evaluating cognitive fatigue in firefighters working a 24-hour shift is lacking. Firefighters are exposed to multiple factors that research has shown results in severe cognitive impairment and effects similar to intoxication. This study indicates the cognitive performance of approximately 22% of firefighters is impaired at the beginning of the day. This percentage gradually increases to 27% by the afternoon. Additionally, at all times of the day the mean response times (460ms on shift, 456ms off shift) are near the cutoff point for what is considered normal. Furthermore, it indicates there is no significant difference between cognitive performance on and off shift. Cognitive performance is sensitive to sleep loss. The firefighters in this study got an average of 5-6 hours of sleep per night, with an average of 2 interruptions (Range 0-67); which is well below the recommended 7-9 hours of sleep. It stands to reason that a focus on improving sleep hygiene may be the best way to reduce fatigue and improve cognitive performance for those in the fire service.

In 2007, the International Association of Fire Chiefs produced a report that indicated fatigue management plans should be implemented across the fire service (Elliot & Keuhl, 2007). Though some fire departments may have addressed this issue and not publicized their action, there is little formal work available on the topic specific to the fire service. The topic is, however heavily researched in fields such as risk management, occupational safety, and industrial hygiene. Recommendations from those fields indicate that ideally a fatigue risk management plan should include eight parts: risk identification, risk control, education, management support, employee involvement, commitment of resources, and compliance review (Cabon et al., 2012; Caldwell, Caldwell, Thompson, & Lieberman, 2019; Gander et al., 2011; Reese, 2016).

Risk identification involves identifying who is at risk and what factors contribute to that risk. Previous research in other fields have identified a variety of biometric variables that can impact fatigue, such as heart (Brake & Bates, 2001; Minard, 1973; Morley et al., 2012), weight (Caruso et al., 2004; Elliot & Keuhl, 2007), and BMI (Brake & Bates, 2001; Caruso et al., 2004; Kales et al., 1999). Underlying health conditions can also affect sleep quantity and quality (Choi et al., 2016; Diez et al., 2020). Evaluations should include an evaluation of daytime sleep in an effort to identify sleep disorders. In addition to individual factors, the workplace should be evaluated for factors that may decrease quantity or quality of sleep obtained at work, such conditions of bunkrooms (comfort of mattresses, temperature, lighting, etc.). Furthermore, workplace policies should be evaluated to optimize rest time and minimize unnecessarily increasing fatigue.

Risk Assessment measures will depend on risks identified at the previous stage. Assessment involves determining the probability the risk will impact the workforce, the severity of the impact if it occurs, and potential ways to control the hazard (Reese, 2016). Assessment will aid in prioritizing control measures and planning implementation of control measures. Ideally, those measures that will have the greatest impact should be implemented first. It may, however, be necessary to plan an implementation schedule according to availability of funds.

Models such as the SAFTE biomathematical model, when appropriately harmonized for use with firefighter populations, could also be used to predict cognitive performance with a variety of shift schedule and/or policy changes, such as later start times, increased nap allocation, and decreasing or increasing shift length. This model has been successfully used to alter shift schedules and policies in the military, railroad, and aviation industries, among others. Once it is fully harmonized for this career field, municipalities could use it to explore their options to more proactively manage fatigue. For example, if overtime were eliminated through the hiring of additional firefighters, they would be able to predict the potential performance changes. Information such as this could be used to inform policy changes, rather than maintain status quo. The data produced could also be useful in supporting budget requests that may be necessary for some changes to be successfully implemented.

Risk Control involves implementing measures that will address the risks that have been identified. These may include alteration of workplace policies, implementation of workplace sponsored health evaluations, development or changes to health and wellness programs, workplace environmental controls, or other appropriate measures.

In this study participants were on shift approximately 37% of the days. This means approximately 2/3 of the sleep obtained occurs at home. Sleep that is obtained at home will affect worker performance. Fire departments cannot effectively dictate what firefighters do at home. They can, however, provide training to employees and their families on sleep hygiene. In one study, 42% of firefighters who participated in sleep training initiative reported making positive changes in their sleep hygiene following participation in the training initiative (Czeisler et al., 2019).

Policies changes and training are a step in the right direction, but they are only as effective as their implementation and enforcement. For training and other control measure to be effective it is important that workplace changes are not just supported by management, but are also consistently implemented. For example, if a napping policy is implemented for one platoon, the same policy should be implemented for all platoons. Management support also means enforcement, which may involve activities to ensure workers are fit-for-duty when they arrive at work.

Employee are more likely to support initiatives that they were involved in developing (Reese, 2016). Fatigue is an issue that affects employees both on and off the job. It can also be exacerbated by factors that are outside the control of the employer, therefore, it is imperative that firefighter be involved with every step of the fatigue management plan.

No plan can succeed without commitment of resources. For fatigue management plans to be implemented effectively, it will be important for Fire Chiefs and all levels of management to allocate resources toward implantation. Resources include both time and money. Completing assessments, training, and other activities that may be indicated by assessment will require time for firefighters to participate. There will also be budgetary impacts to implementing plans. Costs may include hiring consultants, replacing mattresses, training costs, or a whole host of other possibilities. Fatigue management should be a line item on each annual budget plan.

Limitations and Future Research

There are a few potential limitations of this study. The first of which is selection bias. This study sought to collect information on the cognitive performance of firefighters, under the normal conditions in which they work daily. To do that, it had to take place within the working environment, not a laboratory or simulated work environment. For this reason, a convenience sample was used, and therefore participants were not randomly selected. Invitations letters were sent to Fire Chiefs at 20 fire departments that were either geographically convenient for data collection or where the Principal Investigator had contacts; of those, eleven chose to participate. Several who chose to participate did so because they were interested to see a comparison of 24- and 48-hour shifts. Their interest in the results introduces selection bias into the sample.

The selection bias may additionally be increased by the participant recruitment process. Some Fire Chiefs chose to forward my recruitment letter to participants to evaluate their interest in participating before agreeing to participate. They then sent me the contact information for only those firefighters who wanted to participate. Other Fire Chiefs requested live recruitment. They provided space, scheduled a time for each shift to see a recruitment presentation, and required all on the personnel on duty to attend the presentation. Individual firefighters then chose to participate or not. The only motivation that was provided for participants was a small donation to the Fallen Firefighters Foundation for each day they completed all required task (wear the Zulu sensor continuously, complete the journal entries a minimum of four times per day, and complete the PVT a minimum of four times per day). This is a lot to ask of participants, especially for two weeks. Only those firefighters who were willing to commit to the long timeframe and the tedious daily tasks signed up to participate. The sample therefore may be made up of those firefighters who are more highly motivated. This may mean the results are not as generalizable as a random sample would have been.

The second potential limitation is that sufficient date for analysis was only provided between the hours of 8am to 8pm. Though participants worked 24 or 48-hour shifts, and some data was provided throughout the 24-hour time period each day, data was inconsistently reported between the hours of 8pm and 8am. There were not sufficient data points from this time period for valid comparison to other times of the day. In the absence of sleep, it is anticipated cognitive performance would continue to degrade. Future research should build on these findings by gathering data from firefighters at midnight and 4am. This would allow a comparison of performance throughout the entire shift.

This research indicated there is not a significant improvement of cognitive performance on off shift. Although the average cognitive performance was within the range that is considered normal, it was very close to the cutoff point both on and off shift. Available research indicates that the number of days needed for recovery is very career specific. No research is currently available specific to the time needed for firefighters to recover between shifts. For those who work 24-hour shifts, they typically rotate through a series of 24 hours on and 72 hours off the job. Similarly, those who work 48-hour shifts rotate through a series of 48 hours on and up to 96 hours off shift. Additionally, overtime work is often required, which leads to these employees working several days in a row without a day off. With all of this variability, it is important for future researchers to evaluate how much time is needed for firefighters to fully recover.

The results of this study indicate firefighters may be chronically sleep deprived. This makes it difficult to determine the effects of some variables the study sought to evaluate. To observe effects that have been found significant in other studies, as well as to observe the full impact of fatigue firefighters experience every day, it may be necessary to utilize a control group. This group would need to be well rested (non-fatigued) prior to the start of the study. This would also allow the times series analysis to observe the accumulation of fatigue across the full timeframe of the study and comparison between those who are well rested and those who are not. Additionally, a larger sample size would allow for alternative analysis methods such as multiple linear regression

CHAPTER VI

CONCLUSION

Overview

Research shows fatigue reduces the quality of life for those who experience it as well as has costly consequences for employers that include reduced work performance, increased absenteeism, occupational injuries and workplace accidents. Firefighter injuries alone have been estimated to cost approximately $68 million annually (Lexipol, 2018). Though the risk has been recognized for more than a decade (Czeisler et al., 2019; Elliot & Keuhl, 2007; Peterson, 2016), very little formal research has been conducted to evaluate the impact of fatigue on firefighters. Moreover, the research that had been conducted was not generalizable to the majority of fire departments within the US. This research has filled that gap. It has documented the impact of fatigue on the cognitive function of firefighters working both 24 and 48-hour shifts under working conditions that are comparable to the majority of fire departments within the US.

These results indicate more work needs to be done to address the impact of fatigue on firefighters. It is necessary for fire departments to conduct site assessments of the risk they face, as this risk will vary greatly for each municipality. Additionally, it is imperative that fire departments develop and implement a site-specific fatigue management plan to addresses the risks they identify during assessment. Fatigue management plans should, at a minimum, include hazard identification, analysis, and control process, management responsibility and commitment to mitigation of workplace risks, employee involvement in the overall process, education, commitment of resources, and periodic review. Plans will be most effective when they include evidence-based strategies aimed at mitigation of fatigue risk factors both at work and in the home environment. The fire department cannot dictate what employees do on their days off, but they can certainly partner with their employees to education and incentivize them to make changes that will be mutually beneficial. Fatigue has a profound impact on health and wellness; therefore, fire departments may also find it beneficial to partner with health insurance providers for additional resources such as education and monitors. The fire service cannot avoid fatigue entirely, but they can rely on research and lessons learned from other occupations to improve their management of this risk.

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APPENDICES

Appendix A: Initial Survey Questions

Location, fire station #________________________

What is the serial number on the watch you were provided? ______________________

How long have you been a firefighter? ______________________

Which is your regularly assigned shift? A-shift B-shift C-shift

What is your birthdate? _______________________

What is your sex? Male Female

What is your ethnic group?

White Hispanic Black or African American Asian Other (Please Specify)

How tall are you? _____________

How much do you weigh? ______________

Do you have a second job? Yes No

Resting heart rate (relax and sit still for 5-10 minutes before obtaining measure) ______.

Appendix B: Daily Journal Questions

To be completed in the morning at or as near as possible to 8:00 am:

1. Are you on shift today? Yes No

2. If no, are you working a second job today? Yes No

3. Heart Rate: ______________

4. Body Temperature: _______________

5. How would you rate your current fatigue? (Choose the one that most closely describes how you feel):

Fully alert, not tired			A little tired, less than fresh			Completely exhausted, unable to function effectively
1	2	3	4	5	6	7

6. How would you rate your current sleepiness? (Choose the one that most closely describes how you feel):

Extremely alert, not sleepy		Alert		Neither alert nor sleepy		Sleepy, but no effort to stay awake		Very sleepy, great effort to keep stay awake
1	2	3	4	5	6	7	8	9

To be completed at or as near as possible to noon and again at or as near as possible to 4:00pm:

1. Heart Rate:

2. Body Temperature:

3. How would you rate your current fatigue? (Choose the one that most closely describes how you feel):

Fully alert, not tired			A little tired, less than fresh			Completely exhausted, unable to function effectively
1	2	3	4	5	6	7

4. How would you rate your current sleepiness? (Choose the one that most closely describes how you feel):

Extremely alert, not sleepy		Alert		Neither alert nor sleepy		Sleepy, but no effort to stay awake		Very sleepy, great effort to keep stay awake
1	2	3	4	5	6	7	8	9

To be completed at or as near as possible to noon and again at or as near as possible to 12:00pm:

1. Heart Rate:

2. Body Temperature:

3. How would you rate your current fatigue? (Choose the one that most closely describes how you feel):

Fully alert, not tired			A little tired, less than fresh			Completely exhausted, unable to function effectively
1	2	3	4	5	6	7

4. How would you rate your current sleepiness? (Choose the one that most closely describes how you feel):

Extremely alert, not sleepy		Alert		Neither alert nor sleepy		Sleepy, but no effort to stay awake		Very sleepy, great effort to keep stay awake
1	2	3	4	5	6	7	8	9

To be completed at or as close as possible to 8pm:

1. Heart Rate:

2. Body Temperature:

3. How would you rate your current fatigue? (Choose the one that most closely describes how you feel):

Fully alert, not tired			A little tired, less than fresh			Completely exhausted, unable to function effectively
1	2	3	4	5	6	7

4. How would you rate your current sleepiness? (Choose the one that most closely describes how you feel):

Extremely alert, not sleepy		Alert		Neither alert nor sleepy		Sleepy, but no effort to stay awake		Very sleepy, great effort to keep stay awake
1	2	3	4	5	6	7	8	9

5. Which statement best represents your physical workload today?

Call volume much lower than usual		Call volume about the same as usual		Call volume much higher than usual
1	2	3	4	5

6. Have you experienced a workplace injury in the past 24 hours? Yes No

7. If you answered yes on question 6, what was the severity of your injury?

Minor	Moderate	Severe	Life Threatening	Death
1	2	3	4	5

Injury Severity Definitions:

Minor – The patient is not in danger of death or permanent disability. Immediate medical care is not necessary.

Moderate – There is little danger of death or permanent disability. Quick medical care is advisable. This category includes injuries such as fractures or lacerations requiring sutures.

Severe – The situation is potentially life threatening if the condition remains uncontrolled. Immediate medical care is necessary even though body processes may still be functioning and vital signs may be normal.

Life Threatening – Death is imminent: body processes and vital signs are not normal. Immediate medical care is necessary. This category includes injuries such as severe hemorrhaging, severe multiple trauma, and multiple internal injuries.

Death -Dead upon arrival at the scene.

Appendix C: IRB Documents

Oklahoma State University Institutional Review Board

Date:	07/29/2020
Application Number:	IRB-20-320
Proposal Title:	Under the Influence: An Evaluation of the Impact Fatigue has on Cognitive Function of Firefighters Working 24-Hour Shifts
Principal Investigator:	Mellena Nichols
Co-Investigator(s):	
Faculty Adviser:	Marten Brienen
Project Coordinator:	
Research Assistant(s):	
Processed as:	Expedited
Expedited Category:	

Status Recommended by Reviewer(s): Approved
Approval Date: 07/29/2020

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

This study meets criteria in the Revised Common Rule, as well as, one or more of the circumstances for which <u>continuing review is not required.</u> As Principal Investigator of this research, you will be required to submit a status report to the IRB triennially.

The final versions of any recruitment, consent, and assent documents bearing the IRB approval stamp are available for download from IRBManager. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be approved by the IRB. Protocol modifications requiring approval may include changes to the title, PI, adviser, other research personnel, funding status or sponsor, subject population composition or size, recruitment, inclusion/exclusion criteria, research site, research procedures and consent/assent process or forms.
2. Submit a status report to the IRB when requested
3. Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
4. Maintain accurate and complete study records for evaluation by the OSU IRB and, if applicable, inspection by regulatory agencies and/or the study sponsor.
5. Notify the IRB office when your research project is complete or when you are no longer affiliated with Oklahoma State University.

If you have questions about the IRB procedures or need any assistance from the Board, please contact the IRB Office at 405-744-3377 or irb@okstate.edu.

Sincerely,
Oklahoma State University IRB

OKLAHOMA STATE UNIVERSITY
COLLEGE OF
ENGINEERING, ARCHITECTURE AND TECHNOLOGY

Greetings,

My name is Mellena Nichols, I am a PhD student at Oklahoma State University in the Fire and Emergency Management Administration program. Your fire department has been selected to participate in my dissertation study that focuses on fatigue in firefighters working 24- & 48-hour shifts. You are invited to participate in this study because you meet all the criteria for inclusion in the study (rank, age, time in service, shift length). Your participation in this study will contribute to the body of knowledge that is being created on firefighter health and wellness, and may impact future programs aimed at managing fatigue among firefighters on duty. With support from your Fire Chief, I am currently seeking your participation. I have included some information below to help you decide if you would like to participate.

BACKGROUND

The demand for quick response, 24-hours per day, presents the potential risk for some firefighters to work under conditions of extreme fatigue. These conditions may increase the risk of injury and illness among members of the trade. In 2007 the International Association of Fire Chiefs (IAFC) published a report on the impact of fatigue on firefighters. The IAFC recommended that fire departments develop management plans to address this risk. A 2017 Bureau of Labor Statistics report, however, indicates that firefighters are injured at a rate four times higher than all other occupations combined. While career firefighters have adapted and developed abilities to cope and work with little sleep, additional work is needed to create effective management plans. There is no simple fix for this issue and many of the recommendations made up to this point, such as hiring more personnel, is financially infeasible for the average fire station.

PURPOSE OF THE PROJECT

The purpose of this project is to evaluate the impact fatigue has on the cognitive function of firefighters working 24- & 48-hour shifts, to determine if there are any proactive warning signs that may signal intervention is necessary, and to determine how long it takes for the firefighter's cognitive function to return to baseline following their shift. The end goal is to use this information to develop realistic recommendations for recognizing and managing on the job fatigue, thereby reducing risk and costs associated with fatigue related injuries, illnesses, and property damage.

DATA COLLECTION

Participation is voluntary and non-punitive. There are no direct benefits or negative actions for you regardless of whether you decide to participate or not. If you agree to participate in this study, we would ask you to do the following things:

Survey:

You will be asked to answer an eleven-question survey on the first day of the study to collect some basic information about you such as age, years of service, etc. This survey is expected to take no more than 1-2 minutes to complete.

Approved:
Protocol #: IRB-20-320

College of Engineering Architecture and Technology

CONSENT FORM

Under the Influence: An Evaluation of the Impact Fatigue has on Cognitive Function of Firefighters Working 24- and 48-Hour Shifts

Key Information

Study Purpose: The purpose of this project is to evaluate the impact fatigue has on the cognitive function of firefighters working 24- and 48-hour shifts, to determine if there are any proactive warning signs that may signal intervention is necessary, and to determine how long it takes for the firefighter's cognitive function to return to baseline following a shift.

Major Procedures of the Study: Participants will be asked to wear an actigraph watch, complete daily electronic journal entries, and take a short psychomotor vigilance test four times each day for two weeks.

Duration of Participation: Participants will be asked to participate for a full two weeks (14 days).

Significant Risks: There are no significant risks. Minor risks include minor skin irritation and potential breach of confidentiality. Controls are in place to minimize these risks.

Potential Benefits: This study may help the researchers learn more about the development of fatigue during 24- and 48-hour shifts, how much mental impairment can be anticipated from fatigue during the average shift, and whether the scheduled number of days off allows the body to return to baseline following a shift. This information may help in developing effective fatigue management plans that are specifically designed for firefighters.

Compensation: There is no direct compensation for participation in this study. However, to encourage participation, a fundraiser benefiting the National Fallen Firefighters Foundation has been established. Participants can maximize their contribution to the fundraiser by completing all daily activities throughout the two-week study.

Background Information

You are invited to be in a research study of fatigue among firefighters working 24- and 48-hour shifts. You were selected as a possible participant because you work 24- or 48-hour shifts and have been in the fire service for at least one full month. We ask that you read this form and ask any questions you may have before agreeing to be in the study. Your participation is entirely voluntary.

This study is being conducted by: Mellena Nichols, a student in the Department of Fire and Emergency Management Administration at Oklahoma State University, under the direction of Marten Brienen, Associate Professor in the School of Global Studies and Partnerships.

Procedures

If you agree to be in this study, we would ask you to do the following things:

Survey:
You will be asked to answer an eleven-question survey on the first day of the study to collect some basic information about you such as age, years of service, etc. This survey is expected to take no more than 1-2 minutes to complete.

Actigraph:
Actigraph (like a smart watch) is a device that tracks your physical activity and sleep. The actigraph is referred to as the Zulu watch. You will be asked to wear the Zulu watch on your wrist throughout the duration of the study. The watch will calculate your heart rate, record your number of steps, length of time you sleep, and the number of interruptions to your sleep.

Approved:
Protocol #: IRB-20-320

VITA

Mellena Grace Nichols

Candidate for the Degree of

Doctor of Philosophy

Dissertation: UNDER THE INFLUENCE: AN EVALUATION OF THE IMPACT FATIGUE HAS ON COGNITIVE FUNCTION OF FIREFIGHTERS WORKING 24 AND 48-HOUR SHIFTS

Major Field: Fire and Emergency Management Administration

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Fire and Emergency Management Administration at Oklahoma State University, Stillwater, Oklahoma in July, 2022.

Completed the requirements for the Master of Science in Safety, Security and Emergency Management at Eastern Kentucky University, Richmond, Kentucky in 2013.

Completed the requirements for the Bachelor of Science in Occupational Safety and Health at Southeastern Oklahoma State University, Durant, Oklahoma in 2003.

Experience: Assistant Professor of Occupational Safety and Health at Southeastern Oklahoma State University. Safety and Health Specialist for Banda Group International. Safety Supervisor for Ruiz Foods. Environmental Safety and Health Specialist for Choctaw Manufacturing and Development Company.

Professional Memberships: International Public Safety Association, American Society of Safety Professionals, Oklahoma Safety Council, Women in Safety Engineering.