EFFECTS OF OCCUPATIONAL STRESS ON SLEEP ARCHITECTURE AND NOCTURNAL AUTONOMIC FUNCTION IN FIREFIGHTERS AND POLICE OFFFICERS

A Thesis
by
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Abstract

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Firefighters and police officers experience high amounts of occupational stress every day that they are on duty. Increased levels of occupational stress have been shown to affect an individual's sleep architecture and nocturnal autonomic function. This study aimed to observe the difference in these factors in a population of firefighters and police officers during nights they were on duty versus nights they were off duty. A population of firefighters and police officers from the town of Boone Fire Department and the town of Boone Police Department were used as participants for this study. Results illustrated that both sleep architecture and nocturnal autonomic function experienced significant changes when compared with the general population while both on and off duty. It was concluded that the negative impact was due to the high amounts of occupational stress experienced by these two groups.

Keywords: Occupational stress, firefighters, police officers, sleep architecture

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Introduction

Sleep is a fundamental part of determining physical, mental, and emotional health. Studies have shown that sleep is linked to mood, ability to learn, and problem solving, but a deficiency of sleep has also been connected to many physical and mental disorders (NIH, 2015). A deficit in sleep refers to both the quantity and quality of sleep, both of which can be detrimental to health. For most adults, seven to nine hours of sleep that is uninterrupted is considered to be adequate (Sleepfoundation.org, “How Excessive Sleep”, n.d.)

The measurement of sleep involves observing sleep architecture and parameters which include the stages of sleep as well as sleep duration and efficiency and nocturnal autonomic function. Sleep disturbances are regularly experienced by firefighters and police officers and negatively affect sleep quality and quantity (Sleepfoundation.org, “How Excessive Sleep”, n.d.; Koshy et al., 2019; Taran, Sharma, & Bajaj, 2020; Virtanen, 2018).

Sleep Architecture

Sleep architecture defines the cycles of normal sleep and can be divided into two categories: rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep (Sleepfoundation.org, “What Happens”, n.d.). A majority of the night is spent in NREM sleep which can be further divided into 4 stages: N1, N2, N3, and N4 (Park et al., 2000). The final stages of NREM sleep, N3 and N4, are classified as slow wave sleep and is the time during which growth and repair occurs while REM sleep is vital to learning, memory, and stress relief (Park et al., 2000; Sleepfoundation.org, “What Happens”, n.d.). REM and NREM cycle throughout the night about every 90 minutes and this cycle occurs approximately three to five times every night (National Heart, Lung, and Blood Institute, n.d.; Sleepfoundation.org, “What Happens”, n.d.).

Sleep Parameters

Common measurements collected in sleep studies are sleep time (ST), sleep efficiency (SE), time spent in REM stage, N1 stage, N2 stage, and SWS stage, wake after sleep onset (WASO), cortical arousals (CA), autonomic activations (AA), and spindle duration (SD) (Shrivastava et al., 2014). Sleep time refers to the time that is spent asleep and efficiency reflects the percentage of sleep time that was actually spent in sleep stages (Shivastava et al., 2014). Time spent in each stage can refer to the percentage of time spent in each stage or hours spent in each stage during the night. WASO refers to the amount of time spent awake after initially falling asleep and reflects sleep fragmentation (Shivastana et al., 2014). CA and AA are both arousals during the night that are caused by changes in sleep architecture and changes in autonomic modulation respectively. Spindles are powerful synchronous spurts of neuronal firing characteristic of N2 sleep (Andrillon et al., 2011; Kushida, 2013).

Autonomic Modulation

When transitioning from wakefulness to sleep, there is a change in autonomic control. The autonomic nervous system (ANS) is responsible for involuntary actions of the body and has 3 subdivisions; the sympathetic nervous system (SNS), the parasympathetic nervous system (PNS), and the enteric nervous system (ENS) (Waxenbaum, 2019). The SNS is associated with arousal while the PNS dominates in times of rest (Waxenbaum, 2019). Both are always innervating tissues at any given time but a shift in dominance occurs depending on the individual's arousal state. This means that while someone is awake, the SNS is predominantly in control and the PNS is dominant during sleep (Glos et al., 2014; Waxenbaum, 2019). The increase in PNS innervation associated with sleep causes an increase in heart rate variability (HRV), a biomarker for stress, as well as a decrease in heart rate (HR) (Glos et al., 2014; Michels et al., 2012). HRV reflects the ability of the heart to respond to both internal and external stimuli (Michels et al., 2012). The exception to the dominance of the PNS in sleep is during REM sleep. REM sleep is characterized by the rapid movement of the eyes back and forth as well as an increase in sympathetic activity that rivals SNS activity levels seen in an awake state (Glos et al., 2014; Troynikov, Watson, & Nawaz, 2017).

Sleep Disturbances

Deficits in sleep, both in quality and quantity, have been seen to have an adverse effect on productivity, attention, and overall performance in working populations as well as a detrimental effect on physical and mental health (Gaultney, 2014; Michels et al., 2012). Changes in ANS functioning as a result of sleep deprivation can have adverse effects on overall cardiovascular health (Michels et al., 2012). Sleep disturbances can lead to decreased HRV, signifying an increase in SNS modulation and decrease in PNS modulation during sleep (Tobaldini et al., 2017). A predictive association between decreased HRV and increased risk of coronary disease, mortality after myocardial infarction (MI) and all-cause mortality has been reported (Brandenberger et al., 2003). There are many variables that contribute to sleep deficit including the sleep environment and any change in that sleep environment, occupational and personal stress, and personal health.

Firefighters' lifestyle and health

A hectic lifestyle has been associated with a deterioration in sleep quality (Taran, Sharma, & Bajaj, 2020). Firefighters are subjected to high levels of occupational stress and injury. They are exposed to stressors such as smoke inhalation, physically demanding work, sleep restriction, high temperatures, mentally straining situations, and human trauma, illness, and death in their line of duty (Vincent et al., 2018). Physiological and psychological stress is associated with an increased risk of cardiovascular morbidity and mortality. Firefighters occupational exposure to these stressors has rated them at the highest risk of developing cardiovascular disease out of all first responders (Carey et al., 2011). Career firefighters also work on a rotating schedule which means there is a constant change in their sleep environment as well as an increased chance of sleep disturbance due to calls coming in during the night. Depending on the city and state firefighters work in, rotating shifts leave firefighters in the station for fourteen- to sixteen-hour nights (Carey et al., 2011). Firefighters experienced sleep disturbances that put them at a higher risk of susceptibility to fatigue, stress, and cardiovascular risk (Billings & Focht, 2016). One study shows sleep deprivation may reduce microvascular activity by impairing flow mediated brachial artery vasodilation (FMD) (Calvin et al., 2014). Sleep restriction decreased FMD values to those seen in individuals with diabetes, coronary artery disease, or chronic smokers (Calvin et al., 2014). FMD impairment also leads to atherosclerotic build-up and can further the development and progression of cardiovascular disease (Calvin et al., 2014). Prolonged sleep disturbances have also been shown to alter the ANS modulation of sleep (Brandenberger et al., 2003). This alteration will further increase the risk of cardiovascular events and disease as well (Glos et al., 2014).

Police officers' lifestyle and health

Police officers are often subject to rotating twelve-hour shifts which not only disrupts their circadian rhythm but exposes them to occupational stress (Koshy et al., 2019). One study showed that when transitioning from day shifts to night shifts, police officers were only partially adapted to the night shifts after seven consecutive nights on duty as measured by urinary 6-sulfatoxymelatonin, a marker of the central clock (Koshy et al., 2019). Police officers also find themselves having to deal with violence which is associated with higher levels of stress as well as higher levels of sleep disturbances (Garbarino & Magnavita, 2019). Lack of sleep in police officers not only has a detrimental effect on physical health but also on decision making while on the job (Violanti et al., 2017). Occupational stress experienced by police officers can be broken into two categories; job content and job context (Violanti et al., 2017). Job content refers to variables such as shift work (Violanti et al., 2017). Job context refers to the relationships between officers and their coworkers as well as the overall characteristics of the police organization (Violanti et al., 2017). These stressors combined with inadequate sleep, which increases the susceptibility to stress, puts police officers at an increased risk of developing mental disorders such as post-traumatic stress disorder (PTSD), depression, and suicide ideation (Billings & Focht, 2016; Everding et al., 2016). Increased release of cortisol and catecholamines associated with stress also contributes to sleep disturbance creating a cycle of poor sleep and high stress levels among police officers.

Sleep disruption and deprivation are potentially modifiable risk factors that firefighters and police officers face, therefore warranting further research into the effects of work stress on sleep stages. The purpose of this research study is to explore how an individual's sleep architecture and autonomic function are affected based on their work stress and to assess the effects on cardiovascular health as a result of these changes within a community of rural firefighters and police officers. It is hypothesized that career firefighters and police officers will have sleep deficiency due to the nature of their work. This study is of clinical importance because of the links seen between sleep deprivation and declines in autonomic and cardiovascular health. Sleep disturbance and deprivation is often preventable and changing sleep environments to improve sleep quality and quantity is possible. More research is needed to determine the direct effects of occupational stress on sleep as well as the resulting changes in autonomic innervation on the cardiovascular system as a result of sleep deprivation.

Methods

Participants

17 firefighters and police officers, aged 18-65 years were recruited for this study from the Town of Boone Fire Department and Boone Police Department. Participants that were recruited were placed into two occupational groups; firefighters (n = 10) and police officers (n = 7). Exclusion criteria for this study includes age outside of 18-65 and previously diagnosed sleep disorders.

Procedure

All participants filled out an informed consent prior to testing and all experimental procedures were approved by the Appalachian State University Institutional Review Board. Participants came to the Vascular Biology and Autonomic Studies Labs to collect the sleep monitor. An Advanced Brain Monitoring Sleep Profiler™ was used to measure sleep architecture. Participants were given verbal and written instructions on using the Sleep Profiler and told to maintain regular sleep patterns for the three consecutive nights that data was collected. The data was collected for firefighters while either at home after working the dayshift or in the barracks while working the nightshift. The police data was collected at home for three consecutive nights while on dayshift and again for three consecutive shifts while on nightshift. Participants returned to the lab with the equipment where the data was downloaded, the profiler was reprogrammed, and then returned to participants for the next three nights while on the opposite shift. A repeated measures ANOVA by group was run following data collection. Firefighters were divided into two groups; nights spent in the barracks on-duty and nights spent at home off-duty. Police officers were split into two groups; dayshift and nightshift.

Results

Electrodes placed on the forehead monitored electroencephalogram (EEG) activity from the frontal lobe which provided information including; total time asleep, sleep efficiency, REM and slow wave sleep, spindle duration, wake after sleep onset (WASO), and both cortical and autonomic arousals. Nights in which participants were called out were not included. The data was assessed using sleep profiler software following data collection and statistical analysis completed using IBM SPSS Statistics for Windows, version 19. Sleep data for firefighters and police officers on and off duty are displayed in Table 1. Normal values for this population are listed in Table 2 and were provided by the National Sleep Foundation based on subject age.

Table 1. Firefighter and police officer sleep data.

Shift	ST (hrs)	SE (%)	REM (hrs)	N1 (hrs)	N2 (hrs)	SWS (hrs)	WASO (min)	CA	AA	Spindle duration
FF 1 (On duty)	5.2 +/- 2.0	87.8 +/- 4.4	1.1 +/- 0.7	0.4 +/- 0.2	2.7 +/- 1.4	1.0 +/- 0.5	31.8 +/- 17.5	16.1 +/- 15.8	31.0 +/- 17.6	6.0 +/- 10. 3
FF 2 (off duty)	5.7 +/- 1.7	88.4 +/- 3.0	1.1 +/- 0.5	0.5 +/- 0.2	3.0 +/- 1.0	1.1 +/- 0.5	33.8 +/- 17.2	16.4 +/- 7.4	28.3 +/- 11.4	7.6 +/- 7.8
PO (night shift)	4.5 +/- 2.3	89.8 +/- 3.7	1.0 +/- 0.8	0.3 +/- 0.1	2.0 +/- 0.9	1.2 +/- 0.6	26.2 +/- 19.2	14.2 +/- 8.6	32.5 +/- 17.7	5.0 +/- 5.5
PO 2(day shift)	6.6 +/- 1.1	90.7 +/- 2.8	1.2 +/- 0.6	0.5 +/- 0.2	3.5 +/- 1.3	1.3 +/- 0.7	35.0 +/- 10.8	14.6 +/- 5.2	24.6 +/- 18.7	11.2 +/- 13.4

Data are reported as mean +/- standard deviation. ST, sleep time; SE, sleep efficiency; REM, rapid eye-movement; WASO, wake after sleep onset; CA, cortical arousals; AA, autonomic activations

Table 2. Normative sleep values

	ST (hrs)	SE (%)	REM (hrs)	N1 (hrs)	N2 (hrs)	SWS (hrs)	WASO (min)	CA (#/hr)	AA	Spindle duration
Normal	7-9	70-100	1.75 – 2.25	0.35 – 0.45	3.5 – 4.5	1.4 – 1.8	0-45	0-20	0-20	9-12

Data are reported as mean +/- standard deviation. ST, sleep time; SE, sleep efficiency; REM, rapid eye-movement; WASO, wake after sleep onset; CA, cortical arousals; AA, autonomic activations.

Firefighters and police officers had decreased time spent asleep, time spent in REM, time spent in SWS, regardless of shift when compared to age-matched normative values. Police officers on nightshift and firefighters on duty had increased time spent in N1. All groups with the exception of police officers on dayshift had a decrease in time spent in N2 and a decrease in spindle duration.

Discussion

The main finding of this study demonstrates that both firefighters and police officers experience sleep deficiencies when compared to age-matched values, regardless of shift status at levels detrimental to their overall health. This study also shows these populations have a negative adaptation to the decreased amount of sleep they experience. When compared with age-matched normative values, firefighters and police officers experience differences in averages in sleep time (ST), time spent in REM, N1, N2, and SWS, autonomic activations (AA) and spindle duration (SD) that are likely caused by the high levels of occupational stress that police and firefighters are exposed to.

The time spent asleep for all groups was below the normal values of what is considered adequate sleep. The normal sleep range is between seven and nine hours and all groups demonstrated averages below this range (Sleepfoundation.org, "How Excessive Sleep", n.d.). However, sleep efficiency was within normal values suggesting a maladaptation to fewer hours of sleep. While firefighters and police officers are sleeping efficiently for the hours that they are asleep, it is likely that because they are spending less time sleeping, they are not cycling through NREM and REM the amount they should or not spending enough time within each stage of the cycle. Although their sleep efficiency is high, a decrease in sleep quantity still decreases the benefits of restoration experienced in each cycle including memory retention, hormone regulation, and stress relief. This diminished sleep quantity could be due to the alteration in circadian rhythm experienced while on a rotating schedule or from shifting from dayshifts to nightshifts.

Firefighter and police officers also experienced a decreased amount of time spent in REM sleep when compared to normal values. Studies have shown that a deprivation of REM sleep affects brain functioning, specifically impairing the formation of memories as well as the ability to learn, especially when learning motor tasks (Park et al., 2000). REM also supports daytime physical and mental performance which is essential to occupations such as firefighters and police officers (Sleepfoundation.org, “What Happens”, n.d.). Studies have shown mixed results when observing the effect on stress on sleep with some showing a reduction in REM while others showing an increased amount of time spent in REM (Kim & Dimsdale, 2007).

All groups with the exception of police officers on dayshifts experienced a decreased amount of N2 sleep when compared to age-matched normal values. Because this is the point in which regenerative processes start to occur, the PNS modulation increases, and most importantly nocturnal heart rate decreases, a deficiency in N2 sleep can cause an increase in nocturnal heart rate. If this increase becomes chronic, adverse effect on the cardiovascular system may occur (ASA, n.d.). An increased nocturnal heart rate also can signify a change in ANS modulation during sleep. Increased SNS and decreased PNS modulation causes a decreased HRV putting the individual at higher risk for cardiovascular disease (Michels et al., 2012). Police officers and firefighters already have an increased risk of developing cardiovascular disease from their high levels of occupational stress and this risk is further increased due to sleep disturbance (Calvin et al., 2014; Violanti et al., 2017)).

Averages of all groups were below the normal 1.4 to 1.8 hours of SWS a night. It is considered essential for recovery which is why a decrease in SWS can effect physical health (Peever & Fuller, 2016). This is especially important for police officers and firefighters because the high physical demand their work entails and because decreases in SWS have been associated with high levels of stress, for which these populations are at greater risk.

Spindle duration also differed when comparing experimental groups to normal values. Spindles are highly characteristic of stage N2 but can be present in SWS and are associated with memory retention (Andrillon et al., 2011). Studies show that spindles can be classified as fast or slow with spindles in N2 stage oscillating between 9- 16 Hz and spindles present in SWS at a larger amplitude, about 1 Hz (Andrillon et al., 2011). Firefighters, both on and off duty, and police officers on nightshifts, have sleep spindles that occur at higher amplitudes, signifying a higher percentage in the night spent in SWS. In contrast, police officers that work the day shift are the only group with spindle duration in a normal range and they have the highest percentage of N2 sleep when compared with SWS.

Firefighters on duty and police on nightshifts were also spending more time in N1 compared to age-matched normative data. The N1 stage of sleep is extremely light sleep which is easily disrupted meaning a higher percentage of N1 sleep can lead to increases in wakefulness during the night, decreasing both quantity and quality of sleep (Colten et al., 2006).

Wake after sleep onset (WASO) average was in the acceptable range but the standard deviation of firefighters on and off duty, as well as police officers on nightshift suggests individuals in some environments experience a WASO value that is higher than normal. WASO is a parameter that is reflective of sleep fragmentation and represents wakefulness during the night that excludes time before sleep onset (Shrivastana et al., 2014). If this number is high, the individual experienced either longer periods of wakefulness or woke up more frequently during the night. These values were the highest in the firefighters sleeping at home and police officers working the day shift. This is likely due to the increased time spent in N1 sleep by both these groups which is the easiest stage to disrupt. In future studies it may be beneficial to look at individuals rather than pooling an average to develop a treatment for those who are experiencing larger WASO values as well as collect information on participants' perceived stress.

Similar to WASO, cortical arousals (CA) were in the normal range but the data suggest some individuals had measurements above that range. Cortical arousals are a cause of sleep disruption that is the result of altered sleep architecture (Brockman et al., 2010). Sleep disruption may be caused by circadian rhythm disruption experienced by firefighters and police officers while changing shifts or while receiving calls while on shifts.

Autonomic activations are another method of sleep disruption that were high among participants in this study. Autonomic activations are most commonly caused by changes to heart rate and blood pressure (Brockman et al., 2010). An increased number of autonomic activations suggest sharp changes in heart rate and blood pressure, both of which dip at night in healthy populations (Brandenberger et al., 2003). Autonomic arousals suggest a change in autonomic modulation during sleep, which should be dominated by the PNS. These activations seen in police officers and firefighters can lead to further disruption of sleep as well as disturbed behavior and poor job performance (Brockman et al., 2010). These fluctuations are likely attributed to high levels of occupational stress and poor sleep quality or quantity.

Conclusion

In conclusion, firefighters and police officers experience deficits in sleep quality and quantity when compared to age-matched normative values regardless of shift type. There is a clinical difference in the hours spent in REM, N1, N2, and SWS, in time spent asleep, and spindle duration which increases risk of cardiovascular disease and psychological disorders. Firefighters and police officers are already exposed to high levels of occupational stress, which along with rotating shifts, further increase their risk of sleep disturbances. Deficiencies in sleep have been linked to decreases in job performance, poor decision-making, increased stress levels, psychological disorders such as depression, and cardiovascular disease. Further research in this area is warranted due to the nature of work that firefighters and police officers are involved in and their increased risk of cardiovascular disease.

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Vita

Lainey Elizabeth Hunnicutt was born in Concord, North Carolina and moved to Charlotte, North Carolina at the age of 4. She graduated from South Mecklenburg High School in June of 2015 and continued her education at Appalachian State University. There, she studied for her Bachelor of Science Degree in Exercise Science while participating in Varsity Track and Field. In the fall of 2019, she accepted a research assistantship in Exercise Science at Appalachian State University and began study toward a Master of Science Degree in Exercise Science. The M.S. was rewarded in December 2020.

In September 2020, Ms. Hunnicutt began working for Lifescan Wellness Centers located in Tampa, Florida. She works with first responders to ensure they are fit for duty. She performs exercise tests while monitoring EKG's. She currently resides in Tampa, Florida and continues working for Lifescan wellness. She hopes to return to school to gain her Medical Degree eventually.