Physiological and psychological impacts of nighttime call response in firefighters from volunteer and paid-on-call fire departments

by

Thomas W. Service
Bachelor of Science, University of Victoria, 2015

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Supervisory Committee

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Dr. Lynneth A. Stuart-Hill, School of Exercise Science, Physical and Health Education, University of Victoria, BC, Canada.
Supervisor

Dr. Jodie R. Gawryluk, Department of Psychology, University of Victoria, BC, Canada.
Co-Supervisor

Abstract

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An oft overlooked population in research, firefighters of volunteer and paid-on-call fire departments respond to nighttime calls as a supplement to their normal working hours, making the duties taxing on the autonomic system leading to cardiovascular and endocrine disruptions. These duties also come with a tax burden on the volume and distribution of sleep. The current study was executed in order to gain valuable insight into the impact of nighttime call response in this population and the magnitude and duration of any perturbations. Eight firefighters from Greater Victoria Volunteer and Paid-on-call departments were recruited to wear Equivital EQ02 heart monitors and FitBit Charge 2 devices to record autonomic cardiovascular responses and track sleep between 1900 and 0700. HR MAX was found to significantly increase with a large effect size ($p<0.0005$) from 97 ± 20 to 157 ± 18 beats per minute in the 15 minutes preceding versus following a call within the time period. LF/HF ratios increased during the first 15-minutes following a call to 4.055 ± 1.316 from 1.911 ± 0.599 pre-call. HF power, RMSSD, and pNN50 all decreased significantly compared to pre-call values (796.176 ± 414.296 ms^2 vs 244.119 ± 153.880 ms^2, 51.940 ± 7.119 ms vs 35.072 ± 2.624 ms, 25.017 ± 7.034% vs 7.403 ± 2.411%). Further, all HRV measures with the exception of normalized LF and HF were found to be significantly different when waking for and attending a call versus waking on a normal day despite there being no significant differences among any variables when going to bed on nights with and without a call.

Total and REM sleep were the most significantly impacted measurables of sleep. Total sleep fell to 261.11 ± 61.11 minutes from 417.13 ± 52.04 minutes while REM absolute and percentage of total sleep dropped from 109.88 ± 28.47 minutes to 51.44 ± 17.92 minutes, and 22.25 ± 3.73% to 16.33 ± 3.17% respectively. In response to a call, mean salivary cortisol levels increased from pre-call values by 0.426 ± 0.202 μg/dL ($p<.001$). Salivary c-reactive protein levels also showed significant increases with a small effect size, though due to secretion kinetics, call response is not the likely cause. The results of this study demonstrate the presence of a significant shift in autonomic control from parasympathetic (PSNS) dominance to sympathetic control and PSNS withdrawal which evokes a cortisol-mediated stress response of comparable magnitude to literature standards for normal waking fluxes. Sleep volume, and arguably the most critical stage of sleep, rapid eye movement, are significantly impacted and the links between cognitive performance and both total and overall REM sleep indicate that call response does not just impact the cardiovascular system but may in fact be reducing mental acuity of firefighters. This is important as it has the potential to impact both self and team health and safety, not only during night time call response, but at the firefighters’ day jobs which they regularly proceed to the very same morning following a call, evidently with significant deprivation in sleep.

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Chapter 1 - Introduction

1.1) Rationale

Volunteer firefighters are a critical component of their respective communities, providing services at a fraction of the cost of a staffed career department (A. Brunet, DeBoer, & McNamara, 2001; Fire Services Liaison Group, 2009). The per capita costs of firefighting in BC are approximately 1% of the cost for paramedical services. Nation-wide, there are an estimated 170,000 firefighters, 85% of which are volunteers (Haynes, 2016). Further, 80% of volunteers possess their own careers independent of the fire service. Despite these numbers, volunteer-based firefighters are underrepresented in firefighter research; the bulk of research is from studies of career firefighters or a mix of career-volunteer from the United States (Kales, Soteriades, Christophi, & Christiani, 2007).

Relevant Firefighter Research

Firefighter research, and the dissemination of knowledge has typically been dominated by post-hoc studies based on injury and death reports from the National Fire Protection Association or worker's safety panels. Further, studies which aim to provide explanatory information beyond that of a post-hoc study typically do not distinguish between career and volunteer firefighters (Hong, Phelps, Feld, & Vogel, 2012) despite major lifestyle differences (Kales et al., 2007). The result is a paucity of proactive-type studies on occupational stress, both physiological and psychological, and consequently, limited dissemination of preventative techniques to mitigate stress and stress-related injury to fire departments, particularly for firefighters in volunteer-based departments.

Of particular concern is the job-induced stress experienced by volunteer firefighters, who are believed to have more drastic stress responses than career firefighters (Kales et al., 2007). One potential explanation for this belief is the fact that volunteer firefighters are always on call and have no guarantees of call volumes or the timeframe in which they will come. Career firefighters have set work schedules and expect calls during their shifts, allowing premonition to curtail the stress response from a call. This falls in line with previous studies involving physicians, who reported on-call status, particularly overnight, as a primary source of occupational stress (C. L. Cooper, Rout, & Faragher, 1989; Nicol & Botterill, 2004; Sutherland & Cooper, 1992).

The psychophysiological stress firefighting duties induce can result in serious health risks. A 2007 Harvard study found that firefighters at a call can experience up to a 136-fold increase in the risk of death from coronary heart disease relative to non-emergency duties (Kales et al., 2007). National Fire Prevention Agency (NFPA) firefighter fatality reports from 2015 and 2016 identify cardiovascular emergencies as the biggest mortality threat to firefighters, accounting 56% and 38%, of firefighter deaths in the United States, respectively (Fahy, LeBlanc, & Molis, 2016; Fahy, LeBlanc P, & Molis, 2017). In fact, cardiac failure in volunteer firefighters represented 36.4% of the total fatalities in 2015 and 17% in 2016 (Fahy et al., 2017) Part of the decrease can be attributed to an increase in fatalities during call response. Though such reports are useful for looking back at trends, there is still limited knowledge about the individual sources generating increased susceptibility/stress and how it may interact with increases in the risk of disease/injury among firefighters.

An equally important focus for mitigation is the psychological impact of firefighting. A study involving volunteer firefighters on Prince Edward Island found that only 7.8% of firefighters will not attend a single critical incident, but over 34% will attend 20 or more (Brazil, 2017). There is increasing evidence within healthcare that physiological and psychological health are intimately related. As a result, the medical community is transitioning to biopsychosocial models which look at biological, psychological, and social contributions to health. Consequently, investigations of firefighter stress should aim to address both psychological and physiological health implications.

Clarity surrounding stressors and the psychophysiological response, both specifically and respectively, in career and volunteer firefighters, is especially important because of the clear and drastic lifestyle differences between the two groups. Volunteers possess a higher mortality rate during call response in comparison to career firefighters who will typically respond to, and attend, more calls than a volunteer firefighter over the course of a day, week, month, year, and career (Kales et al., 2007). As a result, volunteer fire departments using the mixed-population data to assess risk, may not be presenting the appropriate psychophysiological risks to their firefighters as the career-based firefighter data would dilute the true injury and mortality rates among firefighters within volunteer departments.

Heart rate variability (HRV), salivary stress assays, and the event-related potentials (ERPs) of electroencephalography (EEG) are three validated methods by which one can evaluate physiological and/or psychological stress (Krigolson, Williams, Norton, Hassall, & Colino, 2017; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). In addition, sleep quality analysis provides insight into fatigue and the extent circadian rhythm interruption. Providing multiple metrics for both stress modalities enhances the reliability of the overall analyses.

Since Evgeny Vaschillo pioneered HRV analysis, research has continued to emphasize the importance of high HRV and its association with strong physical and mental well-being (P.

Lehrer, 2013; Xhyheri, Manfrini, Mazzolini, Pizzi, & Bugiardini, 2012). Decreases in HRV are indicators of a myriad of physiological and/or psychological issues that are linked to physical conditioning, stress or anxiety, and discomfort or lack of experience (P. M. Lehrer & Gevirtz, 2014). After the Task Force of the European Society of Cardiology set out guidelines for methodological homogenization, an increasing amount of studies have linked decreased HRV with a variety of conditions, providing validation for research use in both patient and general populations (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). In the parameters of cardiovascular stress, there are strong correlations between HRV and survival rates of individuals post-heart attack, and in those who have yet to experience a cardiovascular emergency (P. M. Lehrer & Gevirtz, 2014; Tsuji et al., 1996). Further, decreased HRV is associated with an increased risk-for and severity-of obstructive coronary artery disease (Liao, Al-Zaiti, & Carey, 2014).

HRV has been highly utilized in the occupational setting and has shown a strong correlation with stress and fatigue. Physicians, pilots, nurses, and surgeons, three highly stressful professions, all demonstrate stress-related decreases in HRV when on-shift and performing their respective duties (Adams, Roxe, Weiss, Zhang, & Rosenthal, 1998; Jones et al., 2015;Borchini et al., 2015). In addition, shift workers experience interruptions in their circadian rhythms, resulting in imbalances which has an adverse effect on resting HRV (Amelsvoort, Schouten, Maan, Swenne, & Kok, 2000).

Salivary cortisol and c-reactive protein (CRP) are each stress biomarkers which serve as indicators of a change in stress levels without utilizing serum. Research shows associations between elevations in stress biomarkers, particularly CRP and cortisol, during cardiovascular and psychological stress. Collecting each metric facilitates the acquisition of important knowledge regarding the mental and physical stress induced by the duties of volunteer firefighting during atypical hours.

This study aims to evaluate the cardiovascular and psychological components of call-related stress in order to identify acute sources of high physiological and psychological stress and their contributions leading to cardiovascular emergencies and psychological crises. A major component of maintaining safety lies in assigning duties in which a firefighter can thrive. Assigning duties to a firefighter outside of their mental and/or physical capabilities has the potential to result in increased physiological and/or psychological stress leading to an increased risk for injury or death. The current study will address this by comparing findings from physiological metrics, gathered before and after call-outs, to the results of administered stress and cardiovascular risk surveys.

The overall effect of call responses, along with the impact associated with specific times and types of calls will be evaluated in order to provide information on the most debilitating times and call types. With this knowledge, a department can heighten sensitivity to stress mitigation following a call with the ultimate goal of preserving or improving the health and wellness, but also safety of volunteer firefighters both on and off “duty”.

1.2) Research Questions and Hypotheses

i) To what degree is autonomic function, measured by Time and Frequency Domain HRV impacted when paged for a call during sleep and what is the duration of perturbation?

H_1: *Call response induces a statistically significant alteration in autonomic function, measured by time and frequency domain variables of heart rate variability, decreasing parasympathetic control while increasing sympathetic innervation.*

ii) Are the call-induced autonomic perturbations noticeably different from those initiated during a normal waking period?

H_1: *Waking to calls produces a significantly greater autonomic response when compared to waking up organically.*

iii) How much is sleep affected when firefighters are woken by and attend a call and are there any critical deficiencies?

H_1: *Call response at night will disrupt sleep quality and reduce overall sleep and each of the three stages measured with statistical significance.*

iv) Do calls result in large surges in salivary cortisol levels?

H_1: *Salivary cortisol levels will increase following a call, rising to levels which are, at a minimum, comparable to those during the normal waking response.*

1.3) Operational Definitions

1.3.1) Mixed Population

A mix, in varying distribution, of career and volunteer firefighters.

1.3.2) Professional Firefighter

A person, either paid explicitly or implicitly, who has received extensive training to carry out the duties of a firefighter.

1.3.3) Calls/Call-outs

Paged-out notifications of active incidents to firefighters through their respective means of delivery such as pagers, apps, etcetera.

1.3.4) Psychophysiology

A division of psychology that links physiological responses with psychological processes such as stress, anxiety, and fatigue.

1.3.5) Heart Rate Variability

Beat-to-beat variation in time between successive heart beats, measured by R-R intervals.

1.3.6) R-R Intervals

Time between successive peaks of an ECG's QRS complex, where R corresponds to the complex's point of peak depolarization.

1.3.7) N-N Intervals

Time intervals between normal peaks (R) of an ECG's QRS complex, where R corresponds to the complex's point of peak depolarization. N-N intervals are effectively R-R intervals with artifact filtration.

1.3.8) Cardiovascular Stress

Sympathetic stress responses resulting in higher demands on the cardiovascular system as measured by HRV and its variables in both Time and Frequency Domain.

1.3.10) Psychological Stress

Emotional or cognitive reactions of a situation that produce or lead to statistically significant physiological responses, measured through scoring of the surveys employed for this study.

1.3.11) Cognitive Stress

The mental component of stress encountered when situation that exceeds a person's range of control or capabilities leading to reduced capacity for reasoning or retention of information (measured but not reported in this context).

1.3.12) Emotional Stress

Emotional tension encountered when one is put in a situation that evokes an emotional response such as anger, sorrow, grief, or fear which can impact the ability to perform mentally and remain composed, particularly under duress. Measured primarily by PCL-5, and to an extent PSS and GAD scores in this study.

1.3.13) Waking Organically

The process of waking up on a normal day, either due to a pre-set alarm or on one’s own free will.

1.4) Assumptions

This study comes with the following assumptions:

- Psychophysiological responses to attending a call are representative of responses to similar call types (fire is similar to motor vehicle incident, similar responses to various types of medical calls).
- Firefighters refrained from drinking caffeine during the monitoring period
- The distribution of age and experience among the study population is representative of the larger pool of volunteer firefighters.
- None of the firefighters had pre-diagnosed mental or physical conditions.

1.5) Limitations

In this study, those who elect to participate will be accepted to the participant pool. As a result, the final population may have a degree of selection bias and may be used more as an exploratory study for the general population of volunteer firefighters province-, nation-, and worldwide. However, if the number of prospective participants exceeds the predetermined target participant number, selection would occur at random following standardized randomization protocols.

There was a relatively low call frequency which limited the total sample size. Calls are sporadic and follow no set pattern.

1.6) Delimitations

Delimitations of this study include selecting a firefighter population that is strictly volunteer. Further, these volunteers will only be recruited from the Greater Victoria area. Monitoring will not be 24-hour for this study, instead a 12-hour period overnight. Methodologically, collection instruments are limited to the Equivital EQ02 LifeMonitor, Salimetrics Passive Drool Immunoassays, and FitBit Alta.

Chapter 2 - Review of Literature and Research Equipment

Approximately 145,000 of the 170,000 firefighters nationwide are volunteer (Haynes, 2016) with 80% of volunteers possessing full-time jobs outside the fire service (Brazil, 2017). The same trend holds in British Columbia, where a 2009 report found volunteers constitute over 71% of the 14,000 firefighters (Fire Services Liaison Group, 2009). The same report noted that per capita costs in the Province of BC for community firefighting was $0.69, less than 1% of paramedical services costs, highlighting the significant savings volunteer firefighters provide to society (Fire Services Liaison Group, 2009). Despite this, much of the existing literature involving firefighters combines volunteer and career populations into one data set or is post-hoc exploratory information leading to reactive, rather than proactive, practices (Hong et al., 2012; Kales et al., 2007). The resultant of this is a paucity of demographic-specific explanatory, proactive research that describes both the "how" and "what" aspects, rather than just the latter. Despite providing significant contributions to their communities and comprising the vast majority of structural firefighters nation-wide, volunteers are especially underrepresented in research, particularly in the USA (Haynes, 2016; Kales et al., 2007).

WorkSafeBC's 2016 injuries & fatalities report found all non-cancer firefighter fatalities, representing 25% of all deaths, were due to either cardiac arrest, or suicide (WorkSafeBC, 2016). In essence, these fatalities were either a result of intense cardiovascular or psychological stress. Further, the NFPA fatality statistics state that 56% and 38% of deaths in 2015 and 2016 respectively were a result of cardiovascular emergencies (Fahy et al., 2016, 2017). From a psychological stress standpoint, one study found that over 34% of volunteer firefighters will attend 20+ critical incidents during their tenure resulting in profound exposure to extreme stress (Brazil, 2017). In order to address the issues surrounding increased cardiovascular and psychological risk, one must determine the physiological and psychological impact associated with call response and how it may result in both acute and chronic deficiencies in health and wellness.

HRV; ERPs; salivary cortisol, and c-reactive protein (CRP); and sleep quality/quantity can be collectively used to evaluate various components of the psychophysiological response to call-associated stress in both short and longer-term time courses.

Due to the diversity of metrics for this study, the following review of literature will be divided sequentially into five main topics: HRV in stress and health; salivary stress/inflammatory markers; ERP and cognitive stress/fatigue; sleep and circadian rhythm disruption; and the knowledge paucities this study addresses in the context of volunteer firefighter research with insight into future steps.

2.1) Heart Rate Variability

Analysis of HRV is a non-invasive method shown to have strong correlations with physiological and psychological well-being (Cysarz et al., 2015; Kemp & Quintana, 2013). HRV is controlled by the autonomic nervous system (ANS) and has been perceived as an indicator of the “see-saw” balance between the two divisions of the ANS: the sympathetic (SNS) and parasympathetic (PSNS) systems (Cysarz et al., 2015). In response to stress, the SNS increases both heart rate and cardiac contractility while the PSNS serves to maintain a calm state with an opposite effect (Ernst, 1996). The intrinsic rhythmicity of the sinoatrial node sets heart rate at approximately 100 beats per minute in a rather metronomic fashion. However, this predictability can be adjusted through input from the SNS and PSNS divisions—the SNS increases whereas the PSNS decreases heart rate—to provide a pattern of inter-beat variability (Gordan, Gwathmey, & Xie, 2015). Resting heart rate is typically 60-75 beats per minute, indicating PSNS dominance at rest (Gordan et al., 2015). In essence, the SNS acts as a gas pedal while the PSNS represents the brake in trying to maintain a contextually appropriate response to demands. When heart rate increases due to increased cardiac workload , the initial event is a withdraw of PSNS innervation, followed later by SNS innervation if the stressor requires further increases in HR (White & Raven, 2014).

HRV is used in assessments of the functionality of the ANS, which controls the body's involuntary and essential functions such as breathing and the heart rate, by revealing SNS-PSNS imbalances (Acharya, Joseph, Kannathal, Lim, & Suri, 2006). ANS imbalances lead to a multitude of disease states both acute and chronic (Palma, Cook, Miglis, & Loavenbruck, 2015). PSNS dominance has been shown to increase the risk of diabetes and diabetic neuropathy and inflammation whereas SNS dominance can lead to exhaustive states through constant heightened energy consumption. This can ultimately lead to sudden cardiac death and other cardiovascular illnesses, premature aging, and an overall earlier morbidity (Malliani, Lombardi, Pagani, & Cerutti, 1994). Studies have also reported that ANS imbalances lead to psychiatric disorders and asthma (P. Lehrer, 2013; P. M. Lehrer & Gevirtz, 2014; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). ANS control over smooth and cardiac muscle make HRV an appropriate measure for evaluating the delicate balance between the SNS and PSNS.

Since the formation of the Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, which led to established parameters surrounding HRV analysis, there has been an increase in the research and clinical application of HRV analysis. In fact, the task force originated during the rise of HRV for clinical and research purposes as a means to develop uniformity in HRV research methodology.

HRV is defined as the variation in time (measured in milliseconds) between a person's heart beats, specifically the R-R interval duration.(Bigger et al., 1993; Ernst, 1996; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996) Small variations in R-R interval is categorized as high variability whereas a relatively consistent time between beats is considered low variability (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996).

2.1.1) Common Domains for Analyzing Heart Rate Variability

HRV data is predominantly displayed in two domains: time and frequency, with guidelines recommending measurements be taken in intervals of 5-minutes or 24-hours (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996) Time-domain is typically used in longer-term analysis due to having a number of short-term measures but also those which typically require a 24-hour recording. Frequency-domain is almost exclusively used for short-term analysis and is commonly used for HRV research due to the ability to assess short-to-moderate time windows, typically 5-minutes in duration (Ernst, 1996; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996; Tsuji et al., 1996). This five-minute interval is typically used in order to consider LF, HF, and VLF; it is recommended that LF be recorded in blocks of two or more minutes, one or more for HF, and five or more for VLF (Quintana et al., 2016; Shaffer & Ginsberg, 2017; Shaffer, McCraty, & Zerr, 2014).

The frequencies which receive the most attention are low frequency (LF), 0.04-0.15Hz; and high frequency (HF), 0.15-0.4Hz.(Amelsvoort et al., 2000; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996)

The ratio of these two, LF/HF, provides a quantitative analysis of the SNS-PSNS balance. A healthy adult's resting LF/HF ratio varies between 1.5-2.0. Below 1.5, there is an imbalance in favor of the PSNS whereas above 2.0 is indicative of perturbation favoring sympathetic activity (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Importantly, to calculate this ratio, one must use normalized units for LF and HF to appropriately calculate the LF/HF ratio. Typical values, though not adjusted for age or sex, are 54 +/- 4n.u. and 1170 +/- 416ms^2 for LF Power (LF_P) and 29 +/- 3n.u. and 975 +/- 203ms^2 for HF Power (HF_P).

Outside of this LF/HF ratio, there is a band referred to as the very low frequency (VLF) band. Research is beginning to pay attention to this frequency band and it has been suggested that it is linked to thermal stress, both hyper and hypothermia, but more so the latter (cite). Further to this, decreases in VLF have been associated with elevated CRP levels and chronic inflammation, which ultimately means a lower VLF in chronically stressed individuals (Carney et al., 2007). In fact, VLF has stronger associations and may be a better predictor of all-cause mortality than HF or LF HRV (Shaffer et al., 2014).

Time Domain analysis is regarded as a more solidified depiction of the interplay of the SNS-PSNS with less contention among interpretation of measurables than the frequency domain with respect to autonomic control/function (Billman, 2013). However, while some time domain variables are reliable in short durations, frequency domain generally provides better and more clear insight into physiological function (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Each of the variables in the time domain are based on the R-R or NN intervals and focus on either the time differences between successive NNs, or the proportion of successive N-Ns that differ by greater than a particular time value.

While SDNN (standard deviation of interbeat, N-N intervals), the pinnacle time domain variable in cardiovascular research, is used clinically in 24-hour recordings due to a higher reliability than shorter durations, it has been used in short-term analyses typically consisting of 5-minute intervals for standardization (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). SDNN shows high correlation with VLF and LF and similar to LF, the primary caveat of SDNN is that both the SNS and PSNS both contribute to its value, making it difficult to discern between true SNS and PSNS-specific activity. As a result, SDNN can be viewed as a correlate of Total Power (Power_T) in the frequency domain.

Standard values for SDNN during a 24-hour recording recognize values according to the following ranges: <50ms is of poor health, 50-100ms deemed health compromised, and >100 as healthy. Normal values for SDNN, independent of age, sex, and environment are 141 +/- 39ms (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). It should be noted that these values may not be as accurate in short-term analysis though as since longer recordings typically correspond to an elevated HRV (Kuusela, 2013). As a result, short durations like a 5-minute or 1-hour recording may drive these standardized values down if not eliminate their reliability in such contexts.

NN50, the number of NN intervals differing by more than 50ms, is analyzed in recordings of 2-minute or greater and while pNN50, the proportion of successive NN intervals differing by more than 50ms, follows similar time course requirements, there have been suggestions of ultra-short one-minute readings. Although, it has been suggested that a threshold for these variables may be more beneficial in discriminating between normal and pathological conditions if set closer to 20ms (Mietus, Peng, Henry, Goldsmith, & Goldberger, 2002). Research has shown NN50 values to be quite age dependent, ranging from 500-2000 (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). As a result, the pNN50 values also are dependent on age.

RMSSD, the square root of the mean squared differences of successive NN intervals, is measured in ms and is typically used s unadjusted normalized values of 27+/- 12ms (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). However, this HRV standard is based off of a 24-hour reading and is highly likely to change when analyzing over shorter terms. RMSSD is influenced by PSNS to a greater degree than SDNN and is correlated with pNN50 but also HF in the frequency domain (Kleiger, Stein, & Bigger, 2005; Shaffer & Ginsberg, 2017). Like other short-term measured variables in the time domain, the standard short-term duration is 5-minutes though research has suggested readings as few as even 10-seconds (Shaffer & Ginsberg, 2017; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996; van den Berg et al., 2018).

One important consideration when conducting HRV research and during comparisons to standardized values is the variation of the normal population's HRV as a function of age. With respect to aging and the trends in the time domain variables mentioned earlier, the average SDNN decreases with age from 153+/- 44ms in those aged 20-29 to 121+/- 27ms in those aged 50-59, demonstrating a trend of decreasing health during aging. This phenomena also holds for PNN50 and RMSSD which decrease from 18 +/- 3% and 43 +/- 19ms to 6+/- 6% and 25+/- 9ms respectively (Umetani, Singer, McCraty, & Atkinson, 1998). From an occupational standpoint, understanding this decrease in HRV is important due to the values roughly representing the normal HRV of those entering the workforce full-time and those who are exiting as retirees. However, to reiterate, when performing any HRV analysis using frequency or time domain, it is imperative that the analysis consist of uniform time-frames across samples to ensure both accuracy and precision of values (Kuusela, 2013).

2.1.2) Equipment for Measuring Heart Rate Variability

With the world increasing in technological advances, personal health monitoring devices are becoming more and more popular. Since 2014, there has been a surging presence of smartwatches, heart monitors, and health apps on the open market.(Reeder & David, 2016) Many of these devices claim to collect HR and HRV data. However, many of these devices have yet to undergo peer-reviewed validation.(Reeder & David, 2016) Heart rate monitors with HR/HRV capabilities, such as polar monitors, are accessible to the general public for purchase and use. These monitors have been highly utilized in the academic community for research despite ongoing controversy as to the effectiveness of such devices relative to true ECGs.

While some studies suggest that polar monitors and other pulse monitors produce recordings with comparable with ECG tracings, others indicate that mobile technology does not provide comparable reliability.(Gamelin, Berthoin, & Bosquet, 2006; Giles, Draper, & Neil, 2016; Guzik et al., 2018) This is due to the lack of precision within pulse rate monitors in detecting the origin of the cardiac cycle and recognition of artifact, thus increasing the difficulty of unambiguous HRV calculation.

While a standard holter monitor for ECG recordings is rather cumbersome due to numerous individual electrodes with wires, pulse rate monitors provide a simple chest strap. However, with this simplification comes the aforementioned controversies in clinical and research accuracy. In addressing this issue, monitors are now emerging which collect HR and HRV data using ECG tracings to provide a blend of reliability and simplicity. One such model is the Equivital EQ02 LifeMonitor, a two-lead ECG monitor chest strap with an additional over-the-shoulder piece to enhance device stability and reliability for measurements.

Multiple studies have examined the validity of Equivital's EQ02 LifeMonitor with positive results, finding accurate ECG and HRV measurements among other physiological variables the monitor is capable of recording.(Akintola, van de Pol, Bimmel, Maan, & van Heemst, 2016; Liu, Zhu, Wang, Ye, & Li, 2013) Such a monitor is capable of recording HR (and subsequently HRV) and respiratory rate, which may aid in reducing controversy surrounding respiratory interference through clearer identification of cardiac cycle origin. One concern from these studies still lies in the presence of content; a variable which influences precision and accuracy of the ECG-HRV recording.(Akintola et al., 2016) In comparisons to holter monitors, Akintola and colleagues found correlation values of 0.724 for all data and 0.955 and 0.997 for less than 50% and 20% artifact, respectively.(Akintola et al., 2016) Thus, mitigation of artifact is a key component of the reliability of the Equivital device despite its 2-lead system. Firefighters being monitored during sleep and task execution may produce a sizeable ECG artifact, in the form of significant VLF band activity, during a standard holter monitor test. However, a snug fit may help reduce the movement of the device during these tasks, subsequently reducing artifact and increasing reliability while another potential option, if feasible for the parameters of the study, is to analyze periods of minimal movement which will possess less artifact.

2.1.3) Stress and Heart Rate Variability

Stress, whether psychologically or physiologically based, evokes an autonomic sympathetic response and concurrent decrease in parasympathetic activity to prepare for dealing with a taxing scenario.(Taelman, Vandeput, Spaepen, & Van Huffel, 2008) Mental stress, though of psychological origin, is accompanied by a number of aforementioned physiological effects as a result of sympathetic activation, including perturbations in HRV. Compared to baselines, execution of mentally stressful computer tasks have been shown to elicit a sympathetic response coupled with parasympathetic attenuation, effectively producing a statistically significant increase in LF/HF ratios (Hjortskov et al., 2004).

2.1.4) Heart Rate Variability in Research

Evgeny Vaschillo first examined the effect of HRV on human's health and performance through data from Russia's space program (P. Lehrer, 2013). He, along with those who succeeded his HRV studies, was able to identify the relation between HRV and personal health and wellness. In recent years, research has continued to reiterate previous hypotheses that a high HRV is preferred due to its connection with better health and performance under pressure, as well as providing insight into the ability to effectively handle and process stress (P. Lehrer, 2013; Xhyheri et al., 2012). Large increases or decreases in HR and HRV are indicators of physiological and/or psychological issues including physical conditioning, stress or anxiety, and discomfort or lack of experience (P. M. Lehrer & Gevirtz, 2014).

Following the Task Force's standardization of HRV analysis, many studies have shown clinical relevance, linking HRV with a variety of conditions and providing validation for research use in both patient and general populations. HRV has a strong correlation with survival rates of an individual post-heart attack; a high HRV is linked to a high resiliency of the heart and cardiovascular system as a whole (P. M. Lehrer & Gevirtz, 2014). After examining individuals possessing lower HRV, research shows that this link persists even in people who have not yet experienced a heart attack or other heart problems (Tsuji et al., 1996). A low HRV, is associated with both an increased risk-for and severity-of obstructive coronary artery disease (Liao et al., 2014). In fact, low HRV is associated with up to a 45% increase in the risk for an initial CV event (Hillebrand et al., 2013). Importantly, HRV also is an indicator of vascular tone and blood pressure – an important consideration for recovery from significant stressors, particularly in occupational contexts where cardiac events occur in the hours following stressors.

The Framingham Heart Study, one of the longest running studies of cardiovascular disease at nearly 70 years, and one of the first users of standardized HRV analysis, discovered LF/HF ratios across all ages, were drastically lower than the lower limit of 1.5 for healthy adults, indicative of ANS imbalance as a result of PSNS dominance (Mahmood, Levy, Vasan, & Wang, 2014). They also found health behaviours such as alcohol consumption, smoking, and low exercise levels in subjects which are not only well-known modifiers of HRV and the LF/HF ratio, but disease -promoting lifestyle characteristics in their own right (Tsuji et al., 1996; Xhyheri et al., 2012).

Outside of clinical use, HRV has been studied in occupational settings, though in limited capacities in firefighting, with documented effects on health and wellness. HRV changes for emergency physicians indicate high levels of stress before and during shift; surgeons performing procedures also present statistically significant changes in the HRV (Adams et al., 1998; Jones et al., 2015). Similarly, beginner pilots during take-off and landing have shown decreases in HRV indicative of high levels of stress and elevated CVD risk (Sauvet et al., 2009). Nurses, who, like firefighters, have to instantly transition from rest to peak performance, have demonstrated decreased HRV as a result of persistent job strain, providing support for the connection between job stress and cardiovascular disease (Borchini et al., 2015). Shift workers in general, like volunteers, are prone to odd work hours and disruptions in their circadian rhythms; their resting

HRV is significantly lower than daytime workers with set schedules, a sign of poorer autonomic function and a possible explanation for their increased cardiovascular risk (Amelsvoort et al., 2000).

In the past decade, firefighters have been increasingly involved with HRV research. A 2014 cross-sectional study of 107 “professional”, common terminology for “career”, firefighters using time-domain HRV analysis, showed a statistically significant association between depression and reduced parasympathetic activity (Liao et al., 2014). However, the study, as noted by the investigators, measured depression and HRV simultaneously, preventing proof of a temporal relationship and a definitive cause-effect conclusion. Despite its ability to evaluate stress responses through SNS-PSNS interplay, HRV has been used sparingly in evaluating call response among firefighters.

2.2) Salivary Analysis of Stress Substances

Salivary analysis of stress substances provides a highly non-invasive means by which to analyze physiological processes. Cortisol, Interleukin-6 (IL-6), and C-reactive protein (CRP) are non-specific biomarkers whose concentration within the body changes in response to stress, among other physiological phenomena (Frijhoff et al., 2015). While these substances are found in the blood stream, saliva is another source of measurement, providing researchers with a collection source that does not require invasive procedures such as an intravenous phlebotomy (Dorn, Lucke, Loucks, & Berga, 2007; Groer et al., 2010; Ouellet-Morin, Danese, Williams, & Arseneault, 2011). The common method is simply a passive saliva drool which is preferred over phlebotomy due to the non-invasiveness and strong correlations between salivary and plasma free-cortisol, CRP (Dorn et al., 2007; Neu, Goldstein, Gao, & Laudenslager, 2007). Chronically high levels of free-cortisol can result in diabetes, truncal obesity, and cardiovascular disease (Whitworth, Williamson, Mangos, & Kelly, 2005).

2.2.1) Cortisol

A number of studies have used cortisol analysis to evaluate stress levels. Chronically high levels of free-cortisol can result in diabetes, truncal obesity, and cardiovascular disease (Whitworth et al., 2005). In relation to HRV, multiple studies have found associations between low HRV, sympathetic dominance, and inflammation, indicating a potential link between inflammation and cardiovascular disease (T. M. Cooper et al., 2015; Lampert et al., 2008). In the occupational setting, research has shown that emergency physicians' evening cortisol levels are significantly correlated with stress, with work load and lack of resources as the major reasons (Baig et al., 2006). In fact, cortisol levels go through a latency phase, continuing to increase and peak beyond termination of the stressful scenario (Qi, Gao, Guan, Liu, & Yang, 2016). The dynamics of this sustained response becomes an issue under repeated high-stress encounters. This is particularly important when stress-related cortisol fluxes occur at night; cortisol levels peak at the beginning of a person's day and will reach daily lows around midnight (Chan & Debono, 2010). Studies report that emergency services personnel who engage in night time response are highly susceptible to perturbation of cortisol's circadian rhythm and higher cortisol levels resulting in increased health risks for the aforementioned diseases (Chan & Debono, 2010; Chung, Son, & Kim, 2011).

Chronic stress in the form of PTSD also has a strong effect on salivary cortisol. Elevated awakening cortisol has been found in police officers with moderate to severe PTSD (Violanti et al., 2007). Such increases relative to the general populations may lead to chronically high levels of cortisol throughout the day, increasing susceptibility to cortisol-related health issues. Directly pertaining to emergency personnel, variations in cortisol response between the response to day and night emergency alarms show no increases before and after an alarm during the day, but a statistically significant increase following a night alarm (Hall et al., 2016). Cortisol plays an important role in alertness; changes in alarm-mediated cortisol response demonstrate a potential change in the physiological response and alarm interpretation by emergency personnel (Chapotot, Gronfier, Jouny, Muzet, & Brandenberger, 1998; Hall et al., 2016).

It is important to review the typical baselines of salivary cortisol to understand typical resting ranges for healthy individuals. A study of 267 healthy individuals found levels of cortisol at 2000h to be 3.9 +/- 0.2 nmol/L while a separate study, sampling 20-40 minutes after waking up, found morning cortisol levels, the period where cortisol is at its highest, in healthy 22 year-old males to be 20.39 nmol/L +/- 7.74 nmol/L (Kobayashi & Miyazaki, 2015; Laudat et al., 1988). Converting to μg/dL, the units given in Salimetrics Salivary Cortisol ELISAs, this corresponds to 0.1414 +/- 0.0072 μg/dL and 0.739 +/- 0.28 μg/dL respectively. Notably, there is a latency phase typically lasting 14-20 minutes post-stressor before cortisol levels spike to a peak concentration (Engert et al., 2013).

2.2.2) C-Reactive Protein

With regards to CRP, whose production can be stimulated by cortisol via IL-6, multiple studies have found that elevated levels in the highest baseline quartile have a three-to-four-fold increase in the risk of a myocardial infarction relative to those in the first quartile (Arima et al., 2008; Rao et al., 2010; Ridker, Cushman, Stampfer, Tracy, & Hennekens, 1997). A 2014 study of career firefighters stated that repetitive events of cardiovascular strain during night shifts, through disruption of cortisol and CRP diurnal cycles, can permanently reduce the body's ability to appropriately maintain cardiovascular homeostasis, putting serious strain on the heart (Choi et al., 2014). However, it should be noted that although it is a strong biomarker for cardiovascular events/disease, as a non-specific stress biomarker, CRP is not as profoundly linked to cardiac stress as, for example, troponin T or I (Gussekloo, Schaap, Frölich, Blauw, & Westendorp, 2000). However, when using subjects as own-controls where the only difference is between pre- and post-call response, there is a greater degree of certainty as to the root cause of an elevated CRP. Changes in serum CRP can take 6-8 hours to occur while peak levels may take up to 48 hours making CRP a good measure for repeated acute and chronic stress (Colley, Fleck, Goode, Muller, & Myers, 1983).

2.4) Sleep Perturbation and Circadian Rhythm Dysfunction

Under normal physiological conditions, the release of glucocorticoids follows a circadian rhythm, as mentioned in section 2.2.1. In this rhythm, cortisol levels are typically at a daily low between 2200 and 0200, peaking between 0600 and 1000 (Oster et al., 2017). The variation in time estimates is wide due to interpersonal variations in circadian rhythm relative to the 24-hour clock. Physiological and psychological stress is known to increase serum, and consequently salivary, cortisol levels through SNS-mediated increases in Hypothalamic Pituitary Adrenal (HPA) Axis activity (Schommer, Hellhammer, & Kirschbaum, 2003). While activation of this axis, particularly with respect to cortisol, originates in the suprachiasmatic nucleus of the hypothalamus, stress initiates activation through the paraventricular nucleus. Stress-mediated increases in corticotropin releasing hormone and the downstream adrenocorticotropic hormone, and cortisol can alter the circadian rhythm which serves critical functions in regulating peripheral clock genes and physiological processes (Kalsbeek et al., 2012). Notably, during the rhythm’s aforementioned nadir, there is a heightened sensitivity to ACTH release which may impact cortisol’s rhythmic release. With this in mind, interruptions which increase cortisol levels during this period may be detrimental to physiological wellness (Oster et al., 2017).

Increases in stress-mediated sympathetic activity in the middle of the night can have a variety of effects on the curve of circulating cortisol. For example, if a firefighter were to receive a call in the early hours of the morning, the morning cortisol spike would occur prematurely with HPA-axis hyperactivity negatively impacting sleep following a call (Buckley & Schatzberg, 2005). Sleep disruption, in this case can result in fatigue which in turn increases diurnal cortisol levels in an effort to promote wakefulness. However, over time, consistent hyperactivity has the potential to exhaust adrenal cells. When these cells are exhausted, cortisol levels effectively flat-line, the typical rhythmic release of cortisol responsible for wakefulness disappears, and fatigue persists (Wilson, 2014). On the other hand, when there is a call prior to sleep, the sympathetic response would increase HPA-axis activity and cortisol production. Hyperactivation of the HPA-axis is suspected to have a causative role in sleep disorders, further exacerbating sleep deprivation (Hirotsu, Tufik, & Andersen, 2015). Thus, it is paramount to understand the impact call response has on cortisol levels, especially at night when cortisol has a heightened ability to impact the proper function of the HPA-axis.

One thing to consider with recording sleep data is the reliability of the device, particularly with respect to detecting and distinguishing sleep and its stages. While there has been criticism of the reliability of the FitBit Charge 2 device for sleep tracking, studies have validated and reiterated its reliability in research applications. The device can detect sleep with specificity of 0.96, 0.61 specificity, and an accuracy of 0.74, though the lower number for specificity is less important in this context as firefighters would be moving sufficiently to ensure recognition of waking (de Zambotti, Goldstone, Claudatos, Colrain, & Baker, 2018). In addition, there is a strong ability to detect the stages of sleep with discrepancies between it and polysomnography typically being an over rather than underestimate. A review of the FitBit technology reiterated that there is limited evidence to support claims of unreliability in sleep tracking (Feehan et al., 2018). With this in mind, erroneous values would detract from reaching significance rather than promoting a type I error.

2.4.1) Sleep and Hours of Work

Work schedules are known to have significant effects on sleep quality and quantity (Ziebertz, Beckers, Van Hooff, Kompier, & Geurts, 2017), including in career firefighters (Billings & Focht, 2016). Generally speaking, "standard" work hours are Monday through Friday and range 0800 and 1700. However, certain professions, notably emergency services and healthcare, prohibit this type of work schedule, requiring around-the-clock staffing in the form of shift and/or on-call work. In the context of sleep, shift work and on-call work, through physiological and/or psychological stress, disrupt the body's biological clock through uncoupling time-dependent HPA-axis activity (Bostock & Steptoe, 2013; Leproult, Copinschi, Buxton, & Van Cauter, 1997). Though volunteer firefighting is more appropriately deemed on-call than shift work, a night-time call spanning a number of hours, or a number of calls in succession, without rest, has the potential to produce a shift-like effect.

Perturbed sleep is the most common health-related effect of shift work; though there is little evidence of shift work leading to chronic insomnia, acute sleep difficulty is common among shift and on-call workers (Dumbell, Matveeva, & Oster, 2016). As mentioned, there is the potential for stress-mediated hyperactivity of the HPA-axis to further impact sleep, leading to further dysfunction in a cyclic fashion. In such instances, a lack of sleep due to a night time call, for example, could impact the ability to sleep following the end of such an event (Hirotsu et al., 2015). With this interruption, there is also, over a prolonged period of time, an increased prevalence of obesity and cardiovascular disease (Szosland, 2010).

2.5) Validated Assessment for Cardiovascular Risk

Framingham's 30-year risk assessment score is a validated assessment tool for evaluating both hard (coronary death, myocardial infarction, or stroke) and full CVD (Pencina et al., 2009). The score generated is a percent based on sex, age, systolic blood pressure, smoking status, whether one takes blood pressure medication, body mass index, and whether or not the person has diabetes (D'Agostino et al., 2008; Pencina et al., 2009). This is advantageous over the 10-year score which requires serum lipid composition values to complete, making it much less invasive.

The 30-year formula by Pencina and colleagues has been used elsewhere in the literature for psychophysiological stress (Gozdzik, Salehi, O'Campo, Stergiopoulos, & Hwang, 2015). The assessment has been shown to reclassify many patients relative to the 10-year score as a result of low consistency between the two but a strong association between the 30-year score and carotid atherosclerotic plaque persists (Masson, Siniawski, Krauss, & Cagide, 2011).

2.6) Validated Surveys for Stress and Anxiety

2.6.1) General Anxiety Disorder-7 Survey

The GAD-7 is a short, validated, and easy to use survey providing context on anxiety within the previous two weeks in both acute care and general population settings.(Löwe et al., 2008; Spitzer, Kroenke, Williams, & Löwe, 2006) As reported by Williams, when setting the threshold score at 10, the GAD-7 possesses sensitivity and specificity of 89% and 82%, respectively, in detecting generalized anxiety (Williams, 2014). The GAD-7 has been used in the emergency services sector, having been employed for an anxiety study of police officers from the September 1, 2001 terrorist attack on the World Trade Center.(Bowler et al., 2016)

2.6.2) Perceived Stress Scale Assessment

The Perceived Stress Scale (PSS-10), developed in 1988 by Dr. Sheldon Cohen, is a validated 10-question evaluation of stress within the previous month (S Cohen & Williamson, 1988; Sheldon Cohen, Kamarck, & Mermelstein, 1983; Ezzati et al., 2014). The PSS has a reputation for being a quick, easily completed and widely-utilized survey (Lee, 2012; Taylor, 2015). Because of these traits, it is a good tool for providing contextual information on a person's stress level, which may affect the total stress profile and related physiological variables.

Though developed and originally validated in the United States, the PSS-10 has been internationally validated and recommended for research or clinical practice in countries in South America and Europe in addition to North America (Andreou et al., 2011; Reis, Hino, & Añez, 2010). The PSS-10 also holds weight in multiple demographics, showing validity in college students and older adults (Ezzati et al., 2014; Roberti, Harrington, & Storch, 2006). One particular demographic where the PSS-10 may lack in reliability is in those with high perceived self-efficacy and low perceived helplessness (Taylor, 2015).

Four of the ten questions in the PSS-10 require reverse ranking as they look at positive associations. Reliability of the 10-question PSS has been shown, thorough a number of studies, to have an alpha co-efficient ranging from 0.78 to 0.85 (Sheldon Cohen et al., 1983; Roberti et al., 2006; K. J. Smith, Rosenberg, & Haight, 2014). To further evaluate reliability, Smith, Rosenberg, & Haight divided the PSS into general distress and ability to cope questions, finding coefficient alpha values of 0.824 and 0.785 for each respective factor (K. J. Smith et al., 2014).

The same researchers used an additional reliability metric, the Spearman-Brown reliability coefficient, which yielded a value of 0.861 (K. J. Smith et al., 2014). Reliability scores of this magnitude, using each respective method, indicate an acceptable-to-strong internal consistency and reliability.

2.6) Current Study in Relation to Firefighter Health and Safety

Approximately 145,000 of the 170,000 firefighters nationwide are volunteer with 80% of volunteers possessing full-time jobs outside the fire service (Brazil, 2017; Haynes, 2016). The same trend holds in British Columbia, where a 2009 report found volunteers constitute over 71% of the 14,000 firefighters (Fire Services Liaison Group, 2009). The same report noted that per capita costs in the Province of BC for community firefighting was $0.69, less than 1% of paramedical services costs, highlighting the significant savings volunteer firefighters provide to society (Fire Services Liaison Group, 2009). Despite this, much of the existing literature involving firefighters groups volunteer and career populations into one data set, or is post-hoc exploratory information leading to reactive rather than proactive practices (Kales et al., 2007). The resultant of this is a paucity of demographic-specific explanatory, proactive research that describes both the “how” and “what” aspects, rather than just the latter.

Firefighters in volunteer-based departments are effectively on-call workers, paged out for firefighting duties at any time, day or night. A number of volunteer fire departments, mostly those with higher call volumes, employ full-time paid firefighters to ensure response times are met during working hours. However, in such cases, the paid firefighters are expected to respond as volunteers outside working hours, contrary to the conventional urban-based paid firefighter.

On-call work, particularly within emergency or essential services is inherently stressful, having to go from rest to peak performance, both mentally and physically, in a matter of seconds. In fact, for the past three years, CareerCast, an employment opportunity database that also provides job rating reports, has found firefighting to be the second most stressful job in America, being narrowly surpassed by Military Enlistment.

While firefighting is a prototypical example of professions demanding such instantaneous transition, other professions experience the same demands and stress. For example, physicians have reported on-call shifts as one of the two most stressful requirements of their profession (Nicol & Botterill, 2004). There is also a significant positive correlation between stress symptoms and on-call work among Finnish anesthetists (Lindfors et al., 2006).

For volunteer firefighters combined with their on-call stress is firefighting's inherent mental and physical stress, possibly increasing risks beyond what mixed-status literature suggest. Regardless, the mental and physical stress for firefighters, particularly on-call volunteers, begins before they even put their gear on. A 2016 study looked the effect of the alarm page on stress, revealing heart rate increases between 2 and 48 beats per minute (MacNeal, Cone, & Wistrom, 2016).

A 2007 Harvard study found that firefighters at a call can experience up to a 136-fold increase in the risk of death from coronary heart disease relative to non-emergency duties (Kales et al., 2007). NFPA firefighter fatality reports from 2015 and 2016 identify cardiovascular emergencies as the biggest mortality threat to firefighters, accounting 56% and 38%, of firefighter deaths in the United States, respectively (Fahy et al., 2016, 2017). In fact, cardiac failure in volunteer firefighters represented 36.4% of the total fatalities in 2015 and 17% in 2016. Part of the decrease between years can be attributed to an increase in fatalities during call response. WorkSafeBC's 2016 injury/death report showed that 25% of the 16 firefighter deaths were a direct result of cardiovascular emergencies or psychological/cognitive impairments, the only non-cancer fatalities (WorkSafeBC, 2016). Though these post-hoc reports are useful for looking back at trends and identifying general problems, we still know little about the physiological sources generating increased susceptibility and how it interacts with the risk levels for firefighters. In essence, they highlight an overall issue, but provide no solutions, pinpoints of potential causes, or increases to the breadth of knowledge.

A further need in the literature is clarity surrounding the influence of stressors and the psychophysiological response in both career and volunteer firefighters. This is especially important because of the clear and drastic lifestyle differences between the two in addition to the fact that two-thirds of line-of-duty injuries are a result of poor situational awareness and/or a lack of health and wellness.(Kales et al., 2007) In fact, lifestyle is suggested to be the primary reason volunteer and career firefighters possess different risks for cardiovascular disease. Further, volunteers possess a higher mortality rate during call response relative to career firefighters who will typically respond to, and attend, more calls than a volunteer firefighter over the course of a day, week, month, year, and career (Kales et al., 2007). This may be due to the fact that career fire departments typically have higher standards of fitness; research has shown positive correlations between physical fitness and decreased risk of cardiovascular (CV) injury/illness and improved mental health (Brazil, 2017; Després, 2016). This may also correspond to resiliency in handling stress, maintaining a lower overall baseline. A study led by Kales nearly a full decade had noted that the two groups of firefighters possess different risk levels, attributing the difference to lifestyle dynamics, including fitness (Kales et al., 2007). However, research continued to keep the two largely grouped together.

From a psychological perspective, a PEI study of 102 volunteer firefighters revealed that critical incident exposure occurs in 92.2% of firefighters over their tenure, and 34% of firefighters had 20 or more instances of critical incident exposure.(Brazil, 2017) Rank, age, and previous exposure had significant negative correlation with participation in post-exposure interventions.

While there is useful information in the literature, there needs to be more clarity in the risks that volunteer and career firefighters face. In addition, while post-hoc studies provide beneficial information, they still are reactionary rather than proactive and do not address the issues being faced head-on. This study helps dissect the acute contributions call response may make in the development of chronic physiological conditions and by quantifying the stress response to the atypical work patterns of volunteer firefighters.

Chapter 3 - Methodology

Participants and Recruitment Procedures

Eight firefighters from volunteer halls, with no selection for gender, race, sex, or religion, were recruited for a quasi-experimental time-series with repeated measures study. Subjects for this experiment acted as their own control with baseline data being collected at variable-dependent time points prior to boarding the fire apparatus for call response.

Participants were recruited from the North and Central Saanich, Volunteer Fire Departments through interactive presentations of approximately 10 minutes. The age ranges for participation were limited between the minimum required age to join the fire service, 19, and 60-years old.

Consent packages were present at the time of the presentation and firefighters were given a minimum of two weeks to decide on participation, complete, and return the package. After the two-week period, the subjects who consented to participation were either equipped with monitors for immediate testing, had a future time for monitoring arranged, or both.

Study Design

This study employed a quasi-experimental time series with repeated measures design. Each participant was permitted to contribute a maximum of three collectable, and usable, periods to the overall pool of results. In order for the results be deemed usable, with the exception of sleep analysis, there must have been at least one overnight call between 1900 and 0700 to which the participant responded to. If there were no calls during a period of monitoring, it did not count as one of their allowable testing periods.

There were single measures for pre and post-call for all metrics with the exception of HRV which possessed a variety of measures. HRV data was analyzed in 15-minute intervals at 0:15-0:00 before a call, and 0:00-0:15 and 1:15-1:30 following dispatch of a call.

Instruments

Multiple methods of data collection were employed in this study. Table 3.1 lists each metric and the specific instrument for collection.

Table 3.1. *Metrics and corresponding instruments employed for data collection*

Variable Recorded	**Instrument Name**	**Measurable Outcome**
Salivary Stress Substance Analysis	Salimetrics Passive Drool ELISA Immunoassay	• Cortisol (Dorn et al., 2007; Groer et al., 2010) • C-Reactive Protein (Slavish, Graham-Engeland, Smyth, & Engeland, 2015)
Heart Rate Variability	Equivital EQ02 LifeMonitor (Akintola et al., 2016) Kubios HRV version 3.1 for data conversion	• LF, HF, & LF/HF Ratio, rMSSD, pNN50 (Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996) • HR
Sleep Quality	FitBit Alta (de Zambotti et al., 2018)	Duration & Composition of Sleep (REM, Light, Awake, Deep)
Anxiety Questionnaire	General Anxiety Disorder-7, GAD-7 (Spitzer et al., 2006)	7-questions Scored /21
Cardiovascular Risk Questionnaire	Framingham 30-year Assessment Tool (Pencina et al., 2009)	30-year Risk for CVD
Stress Questionnaire	Perceived Stress Scale-10 (S Cohen & Williamson, 1988; Sheldon Cohen et al., 1983)	10-questions Scored /40

PTSD Symptoms	PCL-5(Blevins, Weathers, Davis, Witte, & Domino, 2015)	20-questions scored/80

Questionnaires and Risk Score

Questionnaires were provided at the beginning of each monitoring period to provide context to stress baselines. A Framingham risk score was determined using the body mass index formula rather than blood lipids profile. Researchers recorded weight and height for this determination.

Salivary Cortisol & CRP

Saliva was collected in tubes using saliva collection aids, per Salimetrics protocol (Appendix H and I, respectively) and subsequently stored on ice for no more than 1 hour before being frozen at -21°C to maintain viability of samples until a sufficient number of samples were collected to fill the entirety of the sample wells for ELISA immunoassay. Previous research incorporating salivary cortisol collection with oral swabs has provided significant variation in the amount of saliva available for analysis. In some cases, saliva yields were insufficient to properly analyze the sample. During analysis, samples were run using a doublet protocol, as recommended by the manufacturer.

Heart Rate Variability

Monitors were worn from ~1900-0700, including during calls. In some cases, monitors were removed before 0700 if participants had duties that inhibited their ability to keep the monitor on. A daily log was given to each participant so they could track any strenuous, stressful, or other activities but none were noted. Participants were advised to continue the activities of their daily life during the monitoring period.

Sleep Quality

Sleep monitors, FitBit Charge 2 devices, remained on the person during the 1900-0700 period, including calls unless contraindicated by firefighting duties/firefighter safety or if participants needed to remove them for personal reasons.

Procedure

Upon arrival at the equipment fitting, which occurred at their respective fire halls, participants were fitted with both an Equivital EQ02 heart rate monitor and FitBit Charge 2. During this time, they completed PSS-10 and GAD-7 surveys in addition to the open-ended coping question. Age, sex, presence of diabetes, any blood pressure treatments, smoking status were recorded while systolic blood pressure, height and weight were recorded. From these values, a Framingham 30-year Risk Assessment Score was generated, shown in percent of risk.

To increase the certainty of acquiring a true baseline for all parameters, particularly cortisol levels, participants were asked to refrain from physical activity or alcohol consumption for 12 hours prior to baseline data collection. While wearing monitors, participants were asked to keep a log of physical activity and stressful encounters to match with any non-intervention related perturbations. Prior to leaving with the monitors, they were advised of expectations of them reiterated and were provided a phone number to call if they had questions or concerns regarding the device.

When paged out, the participating firefighters responded to their respective fire halls. Within the first 5-minutes of the page, they provided a saliva sample via passive drool which served as their baseline reading. Participants left the sample at the hall to be picked up within 30 minutes and continued with their normal response protocols. Upon return, each participant provided a second saliva sample. Once complete, around 10 minutes in duration, they were discharged from collection and returned to bed or, in some cases, to their daily duties.

Saliva samples were put on ice within 30 minutes and frozen within two hours of collection at -21°C until ELISAs were performed for quantification.

Data Analysis

Heart Rate Variability

To extract heart rate variability data, the Equivital sensor electronics module for the respective participant was synced and the appropriate stored file(s) were downloaded using the Equivital Manager software. The respective night of heart rate data was then exported to Excel. The sheet containing interbeat interval was edited to remove all zero values before being exported as a csv. file for analysis of HRV.

Kubios 3.3.0 software was used to convert inter-beat time recordings to HRV prior to statistical analysis. A filter setting of "strong" was used to remove artifact and extraneous data points. Using this setting corrected any inter-beat intervals differing by more than 150ms at rest, replacing them with interpolated values via cubic spline interpolation. Artifact values were also reported with this version and remained below 11% for all tests.

HRV frequency domain measures were based on Fast-Fourier-Transfer (FFT) waveforms. This process separates the original signal into distinct frequencies like VLF, LF, and HF. This is similar to the Autoregressive (AR) model though it is more favorable as AR tends to employ a stronger filter with regards to outliers that may remove otherwise valid data (Herff & Krusienski, 2018)

Sleep and Sleep Distribution

Total sleep and the amount of light, REM, and deep sleep was extracted from the FitBit Charge 2 device along with the percentage of total sleep spent in each stage, measured by the device's motion detectors and pulse rate technology. In order to extract this info, the FitBit app was downloaded on a device with Bluetooth capability to allow for data transmission from the device to the app. After waking up following each night the monitor is worn, and when in Bluetooth range of a device with the FitBit app, a report is generated that includes each of the above statistics for the given night of sleep.

Salivary Cortisol and C-Reactive Protein

Salivary Cortisol and CRP analysis is a multi-step process using assay protocols that allows for conversion from raw absorbance values taken from a plate reader, to final concentration in µg/dL. Preparation and execution of assays was according to the protocols for each respective assay provided by Salimetrics (Appendix H and I, respectively). Once optical densities (OD) were read in raw form, a correction factor, at a wavelength indicated in the respective assay kits, was used to eliminate incidental OD not related to the substance in question. After this step, averages for all doublets were taken to provide one value.

For calculations of salivary cortisol concentration, after completing the above steps, a correction for non-specific binding (NSB) was done by subtracting each the average of each doublet by the average NSB well value. This yielded true OD values for the zero, standards, high and low controls, and samples. The OD of standards, controls, and samples were then divided by the OD of the zero to determine a bound:unbound ratio. Once these steps were complete, a 4-parameter non-linear regression curve using the 6 standards provided was generated and used to extrapolate concentrations of each sample.

Calculating sample concentrations for CRP consisted of fewer steps after the initial OD reading and correction factor relative to a cortisol ELISA. The CRP assay protocol that was used does not consist of an NSB correction and instead had 8 standards, including the zero compared to the 6 for cortisol. As such, the zero was not used in any bound:unbound calculations. The 8 standards were used to generate a 4-parameter non-linear regression curve fit that was used to calculate sample concentrations based on the average of each sample doublet. Due to dilution in the initial steps of the assay, final concentrations of samples yielded from the curve were multiplied by the dilution factor, in this case, 2X.

Statistical Analysis

All statistical analyses, with the exception of surveys and anthropometric measurements, were conducted in SPSS Version 26 (IBM). Paired t-tests were used to analyze differences between pre- and post-call data for HRV and salivary measures with significance set at 0.05. 95% confidence intervals were reported at all measured points during both control and perturbed states. The one exception to this is in the questionnaires/assessment scores, and physical characteristics of the sample population, where SD is calculated instead. Estimates of effect size for the former set of analyses were performed using Cohen’s d for paired samples.

Sleep-based data was analyzed using a one-way ANOVA, comparing the aforementioned measures of sleep collected, both absolute and percentage values, with the same significance and confidence level as the t-tests. Eta Squared values were calculated in SPSS using univariate analysis of each individual measure for determining effect size among statistically significant differences.

Chapter 4 - Results and Discussion of Demographics/Anthropometric Measures and Survey Scores

Sample Population Characteristics

Eight male firefighters from two volunteer fire departments in the Greater Victoria area attended a total of 12 calls. Initial experimental design expected upwards of 20 firefighters who attended calls. However, less data was collected due to a decrease in the frequency of night time calls during the collection period. The characteristics of each firefighter are listed below.

Table 4.1. *Physical characteristics and experience of participating firefighters*

Participant	**Years as Firefighter**	**Age**	**Height (cm)**	**Weight (kg)**	**BMI (kg/m^2)**
1	5	26	189.3	105.0	29.4
2	1	30	183.6	90.7	27.1
3	27	59	177.1	80.7	25.8
4	15	35	191.3	96.2	26.4
5	6	38	183.4	95.5	28.5
6	8	36	180.7	99.8	30.8
7	8	49	170.2	95.3	33.0
8	3	22	195.5	95.2	25.0
Mean	**9.5**	**36.9**	**183.8**	**94.8**	**28.2**
SD	**8.1**	**12.1**	**8.2**	**7.0**	**2.7**

In order to provide insight and context into potentially elevated baselines or heightened responses to a call, the aforementioned three surveys and a risk assessment score, were administered and scored using the respective validated measures. Table 4.2 depicts both the summarized participant and mean scores for each of the four assessments.

Table 4.2. *Participants' questionnaire and risk assessment score*

Participant	**PSS Score**	**GAD-7 Score**	**PCL-5 Score**	**Full CVD Risk**			**Hard CVD Risk**		
				P	**N**	**O**	**P**	**N**	**O**
1	16	3	3	8	7	5	4	3	2
2	17	2	6	10	9	8	5	5	4
3	13	0	1	40	41	35	27	28	23
4	16	1	5	14	14	11	8	8	6
5	17	2	8	19	17	14	11	10	8
6	20	0	7	19	15	12	11	8	7
7	20	6	6	60	30	25	47	19	15
8	11	2	7	4	4	3	2	2	2
Mean	16.3	2	5.7	**21.8**	**17.1**	**14.1**	**13.4**	**10.4**	**8.4**
SD	3.1	1.9	2.3	**18.9**	**12.5**	**10.8**	**15.3**	**8.9**	**7.2**

O = optimal risk, N = normal risk, P = participant's own risk

One particular aspect to note with regards to the results shown in Table 4.2 is PCL-5 scoring among participants 4-8. In the days before data collection with this group, their department was dispatched to a highly publicized tragic fatality which, more likely than not, could have impacted the PCL-5 scores and possibly PSS or GAD-7 as well. Nonetheless, these findings demonstrate the impact that a single call can have on a person's shorter-term psychological state. In order to evaluate the long-term impact, further investigation is required.

Sample Population Discussion

By tabulating scores for each of the surveys, we were able to draw conclusions as to the firefighters' psychological stress, anxiety, prevalence of PTSD symptoms and even the general population Framingham risk scores for CVD. These findings illuminate the impact volunteer firefighting has on a person's stress, anxiety, and PTSD levels in particular. This may be for a variety of reasons, be it directly due to a call or due to the increased workload experienced by the firefighter as part of their volunteer duties. The volunteer fire departments in this study host weekly practice nights which translates to a minimum time commitment of three hours per week, that is, if there are no calls to add additional time served. However, the values shown in Table 2 must be compared to averages from other populations to provide true insight into where this population fits relative to other groups.

Literature Context: Perceived Stress Scale-14 Scores

PSS Scores among the sample population were found to be lower than anticipated, particularly when considering scores from other populations that compared to firefighting, would be of a lower stress. Interestingly, PSS-14 scores from 1983 among two groups of college students found mean scores of 23.2 and 23.7 with sample sizes of 332 and 114 respectively (Sheldon Cohen et al., 1983). A 2012 study investigating PSS-14 scores in those with traumatic brain injuries found scores of 26.1 in both young and old populations with sample sizes of 81 and 78 respectively. The average sample score of the current study, 16.3 ± 3.1, conveys that numerically speaking, this population experiences lower levels of stress. While this may be possible, there is another aspect to consider.

One explanation is related to desensitization to stress levels which alters HPA-axis activity and attenuates physiological responses (Grissom & Bhatnagar, 2009). This would decrease the threshold of contextual stress resulting in lower stress levels though the stressor would need to be consistent in its type and frequency of occurrence as a number of studies also demonstrate a lack of habituation from short-term stress. However, this theory is somewhat refuted by PSS-14 scores of 108 Indian police constables who scored an average of 27.5 (Walvekar, Ambekar, & Devaranavadagi, 2015). Further, mean scores from a study of 17 firefighters in Portugal were found to be 28 with a standard deviation of 4.99, much higher than the current population mean of 16.3 and standard deviation of 3.1 (Rodrigues, Paiva, Dias, Paulo, & Cunha, 2018).

Though this demonstrates contradicting theories of underreporting stress, potential differences in both the firefighting tactics and lifestyle between North America and Europe may impact self-scoring. Thus, if the scores from the current study are in fact an understated value, a plausible, and possibly more likely, attribution may be a difference in the interpretation of the survey and/or perception of stress itself.

Literature Context: General Anxiety Disorder-7 Scores

Average GAD-7 scores from the sample population were found to be 2 ± 1.9. A survey of 3303 primary care patients in Austria who took the GAD-7 revealed an average score of 4.75 ± 4.76 (Jordan, Shedden-Mora, & Löwe, 2017). Further to this, a study of the validity of GAD-7 in pregnant women revealed scores of 5.7 ± 4.9 in the “no anxiety” cohort consisting of 932 women (Gelaye, Zaslavsky, Fann, Rondon, & Sánchez, 2015). In a study specifically investigating emergency services personnel, firefighters showed the lowest mean GAD-7 score of 4.17 relative to both municipal and Royal Canadian Mounted Police, correction workers, and emergency dispatchers . In fact, the average score of all of these groups combined was still 5.25, much higher than the score of 2 with a variance of 1.9. These examples again show the low levels of anxiety in this population. However, similar to the potential explanations for the PSS-14 scores, desensitization/habituation or perspective. In fact, it has been reported that perspective exhibits a negative association with self-rating anxiety scores (Pozzi et al., 2015).

Literature Context: Framingham 30-year Risk Assessment Score

Framingham 30-year scores using BMI rather than lipid profiles were used for this study to provide some insight into relative cardiovascular health and help explain any potential misnomers. While the raw averages differ in, for example, full CVD risk (own risk = 21.8 ± 18.9, normal risk = 17.1 ± 12.5), there is of course no statistical difference in the population's Full (p=.2867) or Hard (p=.2662) CVD risk compared to normal age-matched values, a finding to be expected considering the very large standard deviations. With a larger sample size though, the standard deviation could eventually decrease to values that may facilitate significance in differences.

PCL-5 for Post-Traumatic Stress Disorder

The PCL-5 test was employed to identify and quantify PTSD-like symptomology. The sample population again scored below both hypothesized values and previously published normative data with a mean score of 5.7 ± 2.3 where a score of 33 meets clinical threshold (Blevins et al., 2015). A study examining PCL-5 scores among two groups, nearly 840 English and 260 French undergraduate students, revealed a mean of 20.9 ± 17.7 and 20.4 ± 16.7 respectively. Conversely, research from 2018 involving PTSD among 100 Canadian helicopter emergency medical services workers revealed a similar trend to what was found in this study. Upon completing the PCL-5 online as part of a mental health study, researchers discovered a relatively low mean PCL-5 score of 6.89 ± 6.80 among 95 of the 100 helicopter personnel who were below the PTSD threshold score of 33 (Harenberg, McCarron, Carleton, O'Malley, & Ross, 2018).

Recent research has shown that nearly half of paramedics may suffer, at varying degrees, from a mental health disorder despite the fact that only 5% of those who completed PCL-5 met the threshold. Further, an emergency services study including firefighters found scores on the PCL-5 to be 16.98 and though the standard deviation was quite large at 16.37, this was the lowest of any of the police, peace officer, or dispatch worker scores (Carleton et al., 2018). Two possible explanations for lower PCL-5 scores among the current study's sample population are simply lower frequencies of critical incident exposure and/or underreporting of mental health symptoms, both of which have been previously proposed (Perrin et al., 2007). In the future it may be beneficial to reiterate to firefighters the importance of accurate reporting and not downplaying their responses.

Chapter 5 - Results & Discussion for Heart Rate Variability Measures

RESULTS: PRE VERSUS POST-CALL CARDIOVASCULAR RESPONSES

Statistical analyses of paired t-tests for comparing pre and post-call data were performed between the 15 minutes preceding a call and both the 15 minutes immediately after a dispatched call and 75 minutes after. However, statistical analysis comparing the two post-call conditions were not performed for this specific study, as the focus was comparing the magnitude of perturbation and whether a return to baseline was rapid or delaye. Figures 5.1 - 5.5 depict the trends of HR and HRV data during this pre-post comparison period, all of which exhibit statistical significance, albeit with varying p-values. It should also be noted that the HRV artifact percentage never increased above 11% and was below 6% for the majority of each 15-minute window reported.

General Cardiovascular Data

Average, minimum, and maximum heart rates were determined for each 15-minute interval along with 95% confidence intervals. Significant differences from pre- to post-call were observed across all three variables and in both of the pre-post conditions with the exception of pre-call HRmax relative to the 75-minute value, as seen in Tables 5.1 and 5.2.

Table 5.1. *Pre-post comparison of the 15-minute recordings immediately preceding and following dispatch of a call*

Variable	Pre	Post	P-value	Effect Size
HR min	50 ± 4	66 ± 6	<.001	1.949
HR mean	60 ± 5	104 ± 13	<.001	2.822

HR max	97 ± 20	157 ± 18	<.001	2.024

Table 5.2. *Pre-post comparison of the 15-minute recordings immediately preceding and 75-90 minutes following dispatch of a call*

Variable	**Pre**	**Post**	**P-value**	**Effect Size**
HR min	50 ± 4	59 ± 6	=.024	1.158
HR mean	60 ± 5	72 ± 7	=.005	1.356
HR max	97 ± 19	98 ± 9	=.895	0.055

Note: P-value is based on a 2-tailed test.

Frequency Domain HRV Perturbations

Fast Fourier Transforms were used for spectral estimation of HRV frequency, providing estimates of power for VLF, LF and HF, and normalized units of LF and HF in addition the LF/HF ratio. When comparing pre-call to post-call data, LF-HF values significantly increased when comparing pre-call and immediate post-call values (Effect size: 1.109) but decreased to a non-significant difference 75-90 minutes post-call (see Figure 5.1).

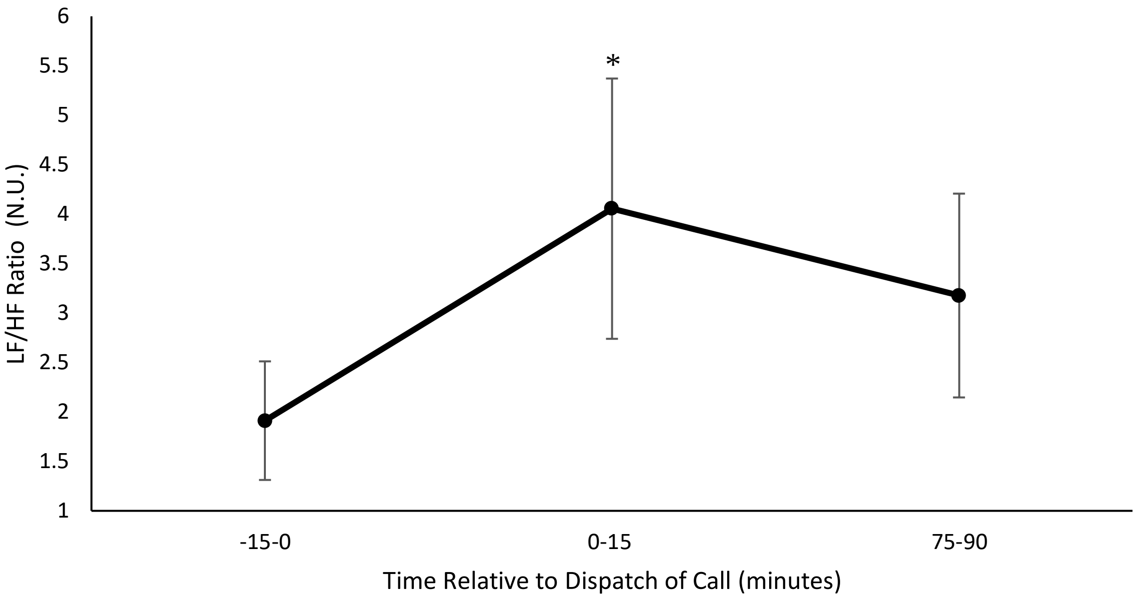

Figure 5.1. Average LF/HF ratio, measured in normalized units over 15-minute intervals, taken immediately before, immediately after, and 75-minutes after call dispatch.

Error Bars = 95% CI, *p=.014

LF_P and HF_P (ms^2) decreased immediately post-call relative to pre-call values, though only HF_P decreased significantly (effect size: 1.767). However, by 75-90 minutes post-call, both had increased and no longer differed significantly from pre-call values (see Figure 5.2).

Total HRV Power over the 15-minute intervals significantly decreased from 2494.3 ± 824.7 ms^2 in the 15-minutes preceding a call-out to 1214.9 ± 518.0 ms^2 in the 15 minutes immediately following (Effect size: 1.180), and increased to 2478.8 ±1095.5 ms^2 75-90 minutes following call dispatch which did not differ significantly from pre-call $Power_T$.

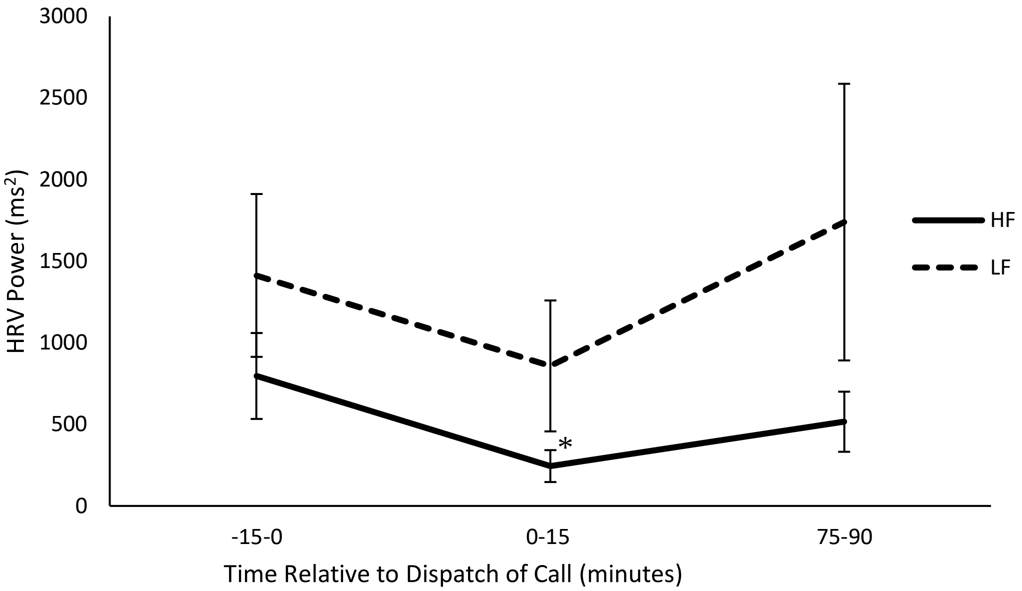

Figure 5.2. Average HF$_P$ and LF$_P$ measured over 15-minute intervals immediately before, immediately after, and 75-minutes after call-out.
Error Bars = 95% CI, *p<.0025

Percent Power$_T$, shown in Figure 5.3, was also calculated for both LF$_P$ and HF$_P$ with significant increases from pre-call LF$_P$ at 0-15 (effect size: 0.807) and 75-90 (effect size 0.936) minutes post-call. Conversely, HF$_P$ decreased, though at a non-significant level (p=.0579) when comparing pre to immediately post values, while 75-minute post-call HF$_P$ was significantly lower than that of pre-call values.

Normalized units of LF and HF were computed but none of the comparisons for either variable reached significance aside from the pre-call and 75-minutes post-call comparison (p<.021) and the immediate pre-post comparison (p=.040) for LF n.u.. Comparisons did not reach significance for HF n.u..

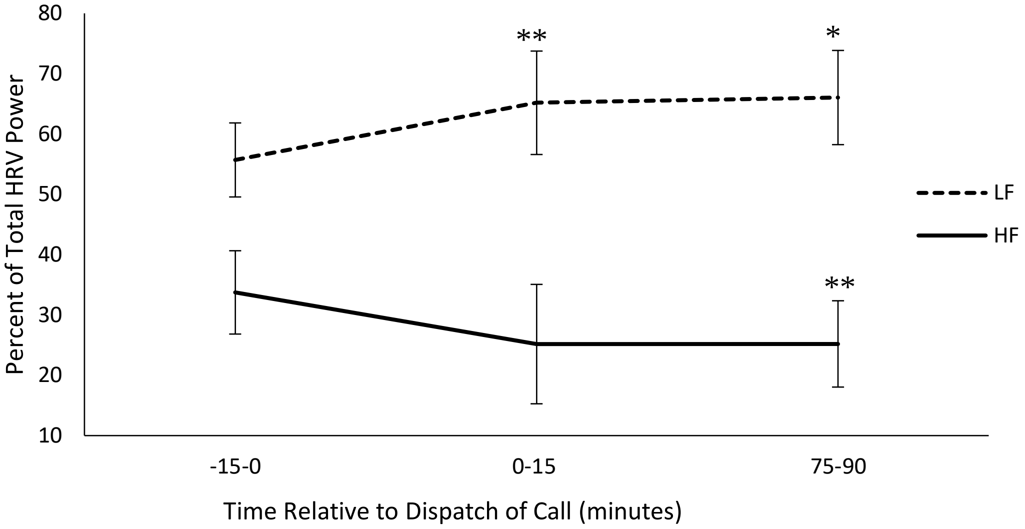

Figure 5.3. Average percent of total HRV Power (ms^2) for both HF and LF measured over 15-minute intervals immediately before, immediately after, and 75-minutes after being dispatched. Error bars = 95% CI, *p<.05, **p<.01

Time Domain HRV Perturbation Results

RMSSD and pNN50 values were also calculated over the three 15-minute intervals, with significant differences only present in the pre -and immediately post-call comparison for both variables, as shown in Figure 5.4 (effect size: 1.998 and 2.129 respectively). However, p-values for both RMSSD and pNN50 values at 75-90 minutes post-call were below .055. Confidence intervals for RMSSD immediately before, immediately following and 75-90-minutes following were found to be 51.940 ± 7.119 ms, 35.0720 ± 2.624 ms, and 44.112 ± 5.809 ms while confidence intervals following the same time course for pNN50 were 25.0167 ± 7.034%, 7.403 ± 2.411%, and 16.982 ± 6.139%.

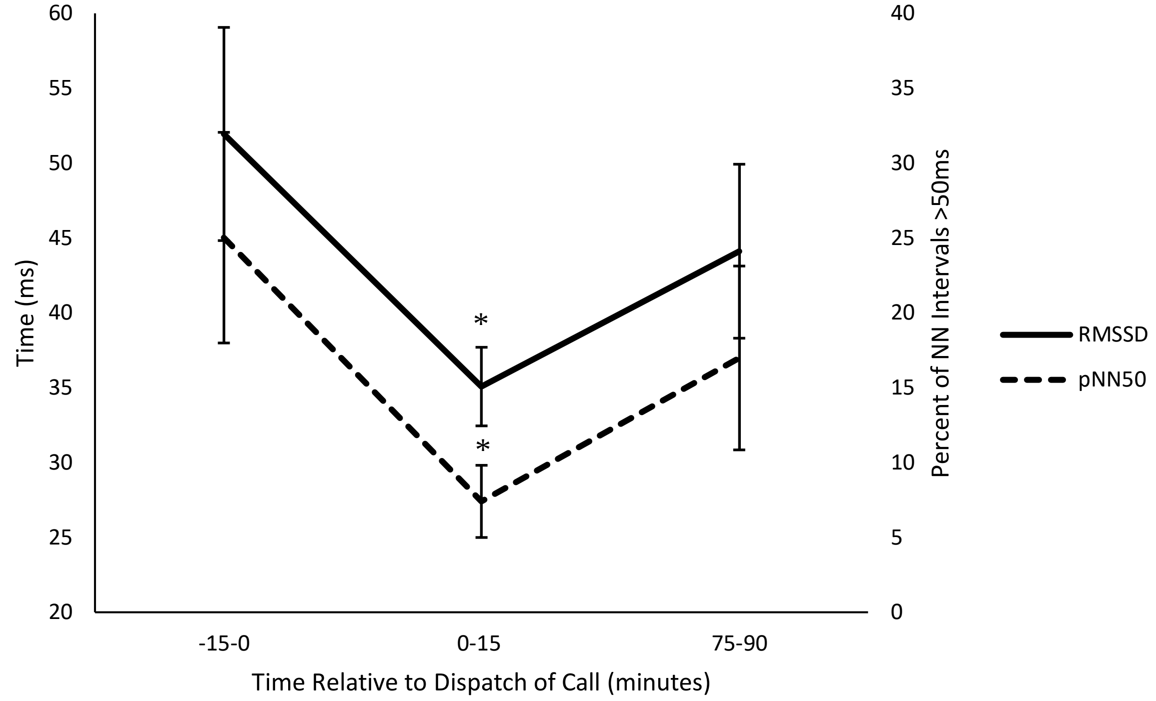

Figure 5.4 Average RMSSD and pNN50 values measured over 15-minute intervals immediately before, immediately after, and 75-minutes after being dispatched.

Error bars = 95% CI, *p≤..001

DISCUSSION: PRE-CALL VERSUS POST-CALL CARDIOVASCULAR/AUTONOMIC RESPONSES

Question I: *To what degree is autonomic cardiovascular control impacted when paged for a call during sleep and what is the duration of perturbation?*

General Cardiovascular Variable Discussion

During call response, there is evident changes in autonomic control causing significant increases in workload for the cardiovascular system. A reduction in PSNS and subsequent increase in SNS activity was observed as HRmax over the first 15-minutes of call response reached 157 ± 18 BPM, well beyond the SA node intrinsic rhythmicity of 100BPM and pre-call resting max of 97 ± 20 BPM, while HRmean immediately post-call was 104 ± 13 BPM.

Calculations of what should be the maximal HR during physical activity (PA) among the current study population based on the average age was 183 BPM. The response to waking to a call induced a HR spike, which was generally observed within the first 1/3 of the monitoring window, to reach 86.3% of exercising maximums. This coincides with findings of a meta-analysis, which found that firefighter stress responses to a call can vary from 84-100% of maximal HR (Perroni, Guidetti, Cignitti, & Baldari, 2014). Notably, the American Heart Association considers vigorous intensity PA to be 70-85% of maximal HR, corresponding to a vigorous PA target range of 146-165 BPM in this population, which barely overlaps with potential values for call-response. In fact, one study found a firefighter whose HR was 188 BPM for a 15-minute period and while two one firefighter reached a maximal HR of 189 BPM during a structure fire call, the duration did not persist past 90 seconds (Barnard & Duncan, 1975).

An important thing to note is the difference in the rate of change leading to HRmax during call response versus PA, irrespective of the cause. When performing PA, there is a warm-up phase that incrementally increases cardiovascular workload, introducing the body to changes, a luxury that is not experienced during emergency call response. The HR during call-response has been shown to reach 80% of maximal HR within the first minute of donning personal protective equipment (Perroni et al., 2014). Firefighters, almost instantaneously, switch from resting HR to values approaching maximal HR, challenging the cardiovascular system to rapidly compensate for increased output demands and spikes in pressure. This rapid increase in heart rate significantly and almost instantaneously increases the load placed on the heart and cardiovascular system, an event that not even world-class athletes endure, and increases the risk of cardiovascular injury. This increased workload, as shown in this study, persists for 75-90 minutes following a call, with the exception of HRmax, highlighting a possible latency in restoration of normal autonomic control of HR. However, there is a possibility this may also be explained by tasks at the fire hall-post call that may have augmented elevations in HR.

Research investigating the physiological stress response to an emergency alarm in 16 adults using Polar Team2 Monitors reported a peak heart rate of 122 BPM with a standard error of 5 BPM during a night alarm compared to 93 ± 6 BPM (Hall et al., 2016). Comparing this to the current study, it appears that the sound of a paged tone is only one component of a waking response and that the nature of the call conveyed may play a role in the extent of sympathetic activity. In addition, significant differences in HR immediately before the alarm were seen up to 3.5 hours post-alarm. This is much longer than that of the current study but could be explained by the tasks being completed by firefighters immediately before the 75-90-minute post-call recording, the potential for habituation and improved PSNS/autonomic control, and/or the discrepancy between pulse monitors and ECG-based systems.

What is known though is that call response effectively mimics the cardiovascular workload, at least in terms of HR, seen during a bout of vigorous or moderate-to-vigorous PA lasting less than 75 minutes. However, while numerous benefits are seen during exercise of this intensity, including resiliency during periods of non-PA stress, the perturbations induced by the latter have been shown to be detrimental to the cardiovascular system by stimulating the release of inflammatory substances and increasing both heart rate and blood pressure, more notably over prolonged and/or repetitive exposure (Huang, Webb, Zourdos, & Acevedo, 2013; Kim, Cheon, Bai, Lee, & Koo, 2018). Research surrounding the impact of shorter duration and/or those with lower frequencies of occurrence may provide better insight into any chronic impacts.

Frequency Domain Perturbation Discussion

LF/HF ratios from this study increased significantly only during immediate pre-post comparisons, rising from 1.911 ± 0.599 to 3.696 ± 1.316, beyond the normal resting values of 1.5-2, though this returned within normal ranges by 75-minutes post-call. In fact, the pre-call ratio itself is somewhat high considering the ratio during sleep should generally be at or below 1. However, this does depend on sleep stage, as mentioned earlier, meaning the recorded value is reasonable. Matching for similar types of stressors, a recent study of LF/HF ratios during firefighter response found ranges between 1.92 ± 0.68 (SD) and 2.85 ± 1.56 (SD) depending on the type of call, though notably on a longer time-frame of measurement than the current study which may have reduced the ratio. While it is difficult to compare directly with other values reported in the literature, as differences in the measurement duration can perturb values, the data shows an obvious decrease in PSNS and what appears to be a concurrent increase in SNS activity. Of further note is the autonomic resilience demonstrated by the rebounding of HRV within 75 minutes following perturbation.

While changes in HF_P and LF/HF ratios occurred as hypothesized, observed drops in LF_P and $Power_T$ were not. Power analyses for LF and HF were also reported due to insignificant differences at both one and two-tailed tests across both normalized LF and HF, with the exception of pre-and 75-minutes post-call comparisons ($p<.021$) and the immediate pre-post comparison ($p=.040$) for LF n.u. possibly due to the observed decreases in total power which has previously been attributed to respiratory sinus arrhythmia (RSA) and is ultimately a component of vagal control (Shaffer & Ginsberg, 2017). This may be a result of an attempt to control breathing during stress; Equivital devices measure respiratory rate making this an interesting avenue to venture in the future. Immediate pre-post call comparisons of VLF showed significant decreases on a one-tailed test (p=.054) indicating that the decrease in LF$_P$ was not due to a frequency shift but rather another phenomenon likely related to total power.

Knowing this, the percent of Power$_T$, including VLF$_P$, for both LF$_P$ ms^2 and HF$_P$ ms^2 was investigated for further insight. These comparisons revealed an increase in proportional LF$_P$ and, as expected, a decrease in HF power immediately following call dispatch with LF$_P$ increasing further in the 75-minute post-call recording. While there was one-tailed significance in pre and 75-minute post-call comparison but not the immediate pre-post comparison, a standard deviation of 11.26 and 15.57 respectively appears to have impacted significance for the latter of the two comparisons. This large variance is due to ¼ of the data having had HF % input of over 45% while the range of the remaining 8 samples' HF ranged from 11.620 - 28.612%.

The optically puzzling finding of decreased LF$_P$ immediately following a call can thus be explained by a lower total power, likely attributed to RSA and/or changes in baroreceptor activity relating to stress related blood pressure modulations (Mccraty & Shaffer, 2015; Shaffer & Ginsberg, 2017).

The majority of data surrounding normal ranges of LF and HF is reported in normalized units. However, this makes it difficult to compare for definitive proof of change in the context of this study as there were minimal changes in normalized units but definitive changes in the proportion of total power for both LF$_P$ and HF$_P$ including VLF$_P$ rather than normalized units which omits it. However, what is clear based on the modified n.u. values is that LF input increases, representing an increase in sympathetic input, while HF, an undisputed component of PSNS activity, significantly decreased (Shaffer & Ginsberg, 2017; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996).

Time Domain Perturbation Discussion

While Frequency Domain HRV is typically used for shorter term analysis, RMSSD and pNN50 scores have the ability to be used with reliability in short-term measurements less than the 15-minutes used in this study. Similar to the Frequency variables discussed, the Time Domain HRV variables exhibited a rebound effect between the two post-call measurements. RMSSD values decreased from 51.940 ± 7.119 ms pre-call, to 35.072 ± 2.633 ms immediately post-call, and increased to 44.112 ± 5.809 ms 75-90 minutes post-call.

These values seem to coincide with RMSSD scores of hospital workers during working hours (25 ± 10, reported as SD) and at night (40 ± 20, reported as SD). RMSSD scores well below 10ms taken from a study that used 2-minute recordings highlight the importance of using similar time courses for comparisons and knowing what devices may have been used (Hintsanen et al., 2007). A meta-analysis by Castaldo et al. (2015) regarding stressed RMSSD in relation to control values found that RMSSD under duress was significantly lower ($p<0.05$) but varied in its average value, ranging from 28.74-74.20 under control conditions and 19.39-57.20 when stressed. Again, these values lend reliability in the measures utilized, but the measuring duration was 30-300 seconds in duration versus the 900 in this study. The observed decrease in this study is as expected considering that RMSSD is correlated with HF and is a Time Domain measurement of PSNS activity (Shaffer & Ginsberg, 2017).

pNN50 values for this study also exhibited a decrease in value. Normal values (mean ± SD) based on a 24-hour recording vary based on the time and activity. For example, in one study, pNN50 during sleep was measured as 15 ± 15.6 % while normal waking values were 4.2 ± 4.9% (Mietus et al., 2002). Though this is over a longer time period than the current study, it does allow for consideration of the trend and approximate values and the validity of the data relative to the literature. Additionally, the meta-analysis previously mentioned when discussing RMSSD also investigated pNN50, which itself is another correlate of PSNS activity (Castaldo et al., 2015; Umetani et al., 1998). Further, pNN50 values significantly decreased during stress in one particular study, from 39.37 ± 23.79% to 20.57 ± 19.04%. Though this is a fairly large standard deviation accompanying the means, it does share common values with this samples' stress-induced decrease from 25.017 ± 7.034% to 7.40 ± 2.411%. The sharp reduction in this variable demonstrates the marked sympathetic response to call dispatching, but the return of pNN50 to pre-call values in this study is somewhat controversial as the one-tailed p-value =.055 comparing pre-call to 75 minutes post-call still produced a medium effect size of 0.773 with an average difference of 8.035 ± 9.872. This is important to note as a 15-minute interval may not always be a true summary of the ongoing process.

In one occupational study, surgeons on 24-hour rotations had HRV recorded over 10-minutes before, during, and after their shift. pNN50 values actually increased over this time as did RMSSD, with significance despite significant decreases in HR (Langelotz, Scharfenberg, Haase, & Schwenk, 2008). This once again demonstrates an increase in PSNS activation and the positive associations between RMSSD and pNN50, but also lends support to the notion that these two variables decrease with heightened SNS activity.

RESULTS: WAKING TO A CALL VERSUS DAILY WAKING ROUTINES

While the results of the call response time series data incorporated 12 calls worth of data, comparisons looking at the differences between waking to a call and waking organically used 8 paired samples, one night being woken from sleep by a call, and one night without any call to respond to. Analysis of the 15-minutes before going to bed on nights with and without a call was performed, revealing no significant differences among any of the variables measured with p-values ranging from 0.208 to 0.970. However, the call-induced wakening response showed significant differences relative to a normal waking response.

General Cardiovascular Perturbation Results

In comparing waking HR during call response with a standard day, MIN (66 ± 8 vs 52 ± 6), MEAN (108 ± 11 vs 67 ± 12), and MAX (158 ± 15 vs 100 ± 14) HR were significantly higher when waking to a call with respective effect sizes of 1.560, 2.132, and 2.383 (see Figure 5.5).

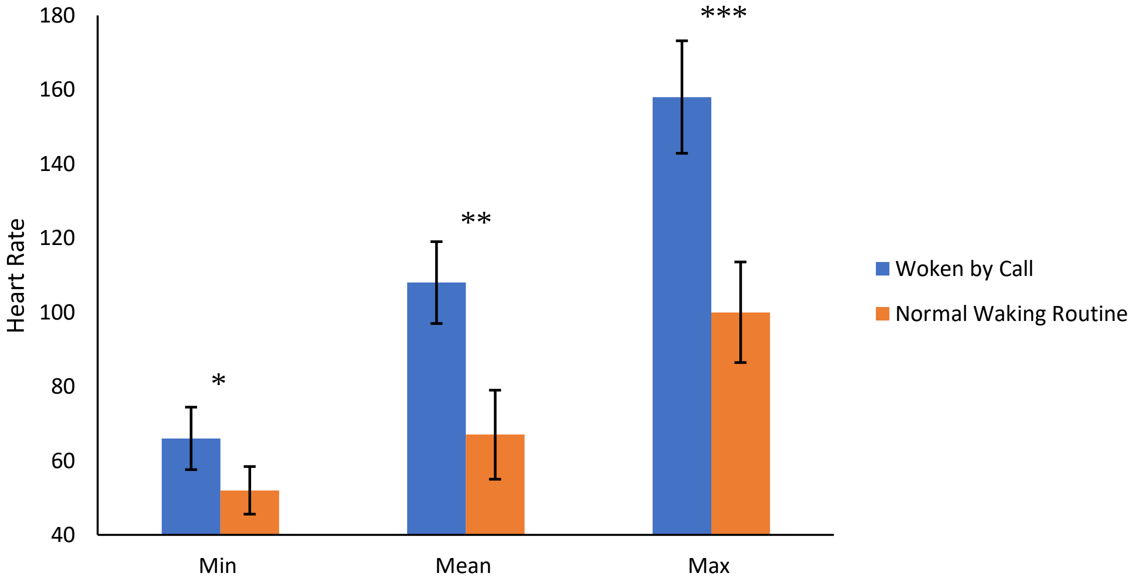

Figure 5.5. Minimum, mean, and maximum heart rates measured over 15-minutes during the normal waking process and upon waking to a call.

Error Bars = 95% CI, *p<.038, **p<.006, ***p<.002)

Frequency Domain HRV Perturbation Results

LF and HF power analyses, shown in Figure 5.6, also held significant differences, with lower values for both variables in response to a call with effect sizes of 1.441 and 1.383 for LF and HF respectively. Further, Total HRV Power was significantly lower upon waking to a call

(1092.2 ± 585.2 ms^2, d =1.650) than when waking up normally (2810.2 ± 1083.5 ms^2). Interestingly, there was no significant difference in comparing LF or HF% of Total HRV Power across the two conditions.

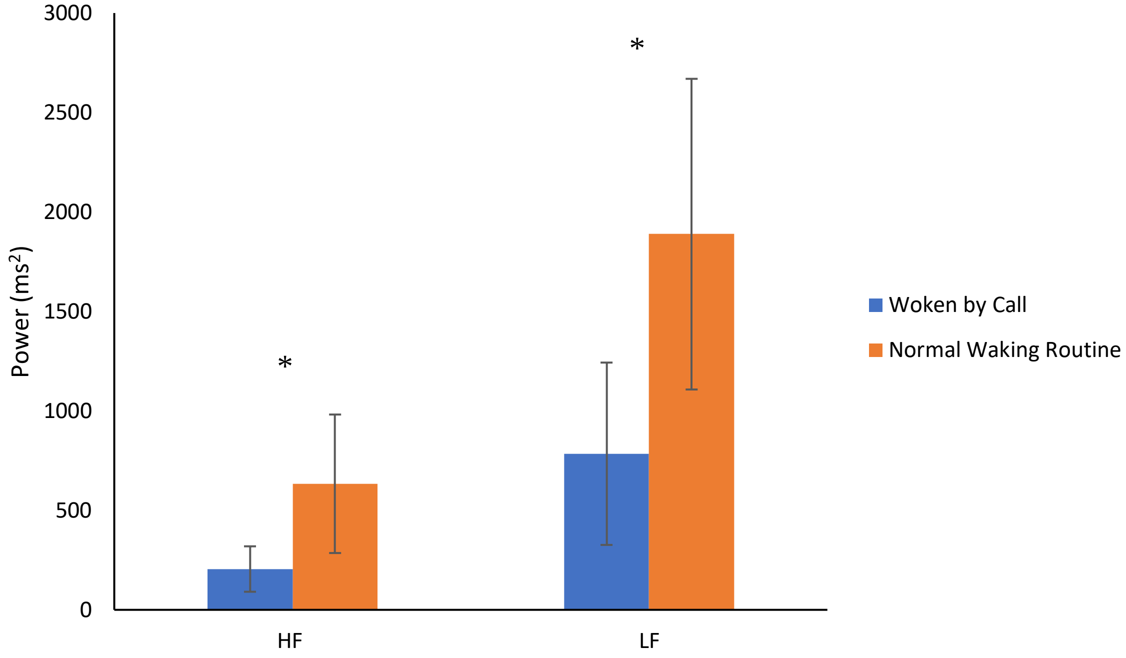

Figure 5.6. LF and HF power measured over 15-minutes during the normal waking process relative to waking to a call.
Error Bars = 95% CI, *p<.03.

Time Domain HRV Perturbation Results

RMSSD and pNN50 values when waking for call response compared to waking normally were also investigated. Significant decreases, shown in Figures 5.7 and 5.8, were found for both RMSSD (effect size: 1.263) and pNN50 (effect size: 1.381) when waking to a call versus waking up on a normal day.

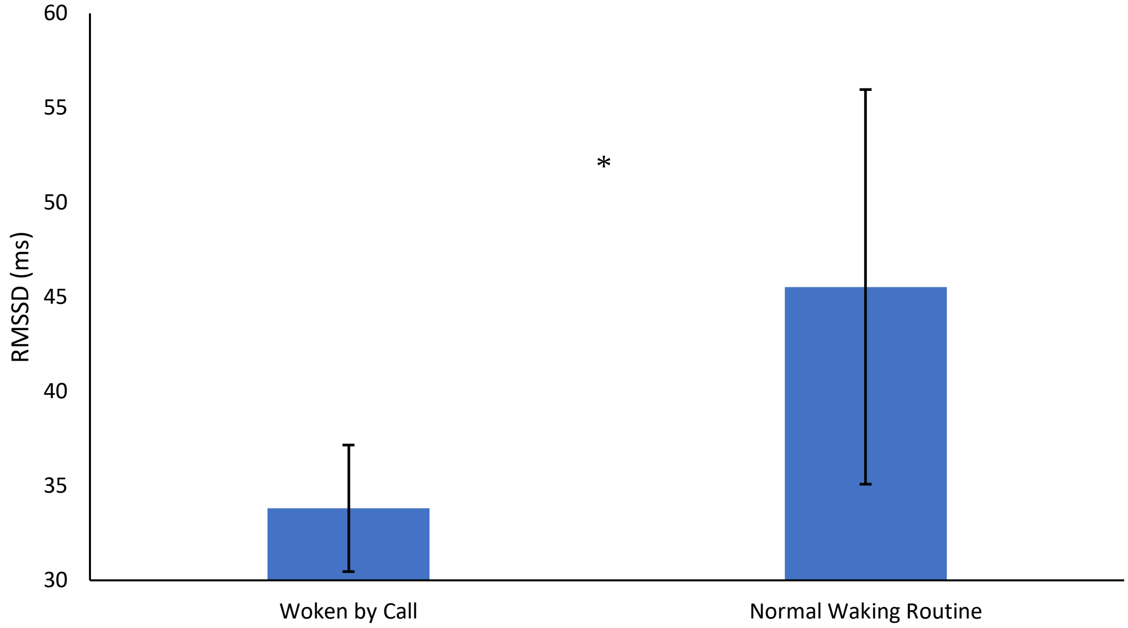

Figure 5.7. RMSSD in the first 15 minutes of waking up to a call versus in comparison to waking up on a normal day.

Error Bars = 95% CI, *p = .045

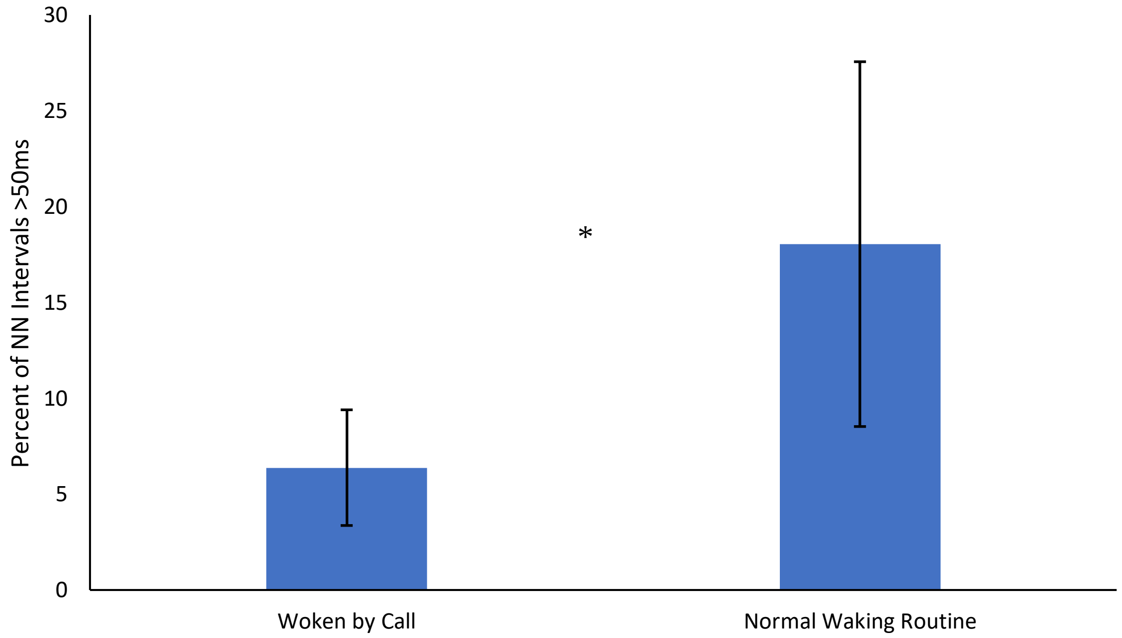

Figure 5.8. pNN50 comparison between waking up for a call and waking up normally, measured over 15-minutes.

DISCUSSION: WAKING TO A CALL VERSUS NORMAL WAKING ROUTINE

Question II: *Does the autonomic response to waking up for the dispatching of a call differ from that of one's normal waking routine such as an alarm clock?*

General Cardiovascular Variable Discussion

As mentioned, literature reported HRmax during call-response can reach 84-100% of the maximum exercising HR. In this population, a HRmax of 158 ± 15 (different from 157 in previous comparisons due to requirements of sleep pre-call in waking up to a call versus waking up in the morning) and HRmean of ± 11 during a call was found to be significantly different than HR upon waking without call stimuli. HRmin also was significantly higher when waking for call response compared to waking up as normal.

Such comparisons are critical in evaluating whether previously discussed changes in the first 15-minutes of a call are due and/or comparable to the natural waking process, or if additional cognitive, emotional, or physiological stress pertaining to the call is responsible for the discrepancy. Findings from a 1975 study support the notion that sound of a call alarm itself is sufficient to drastically increase HR by an average of 47 and range of 12-117 BPM (Barnard & Duncan, 1975). In contrast, the HRmean of 67 ± 12 BPM during a normal waking period appears to coincide with one study's waking HR of 78 ± 9(SD) in a sample of 45 men with an average age of 34 ± 4(SD) years, comparable to the current study (Hautala et al., 2010). As a result, it is entirely reasonable to conclude that the autonomic response controlling heart rate when waking to a call differs significantly from that of a standard waking response.

Frequency Domain Perturbation Discussion

With respect to waking to a call versus normal waking LF_P, HF_P, $Power_T$, and both LF and HF % of Total Power (including VLF_P) were significantly different compared to waking controls. However, normalized units for LF and HF as well as LF/HF Power did not differ significantly. Differences in total power between waking controls and waking to a call were found to be 1718.072 ± 1265.314 ms^2. One possible hypothesis for this, touched on in a review of HRV by Shaffer & Ginsberg (2017), is alterations in baroreceptor function/sensitivity (BRS) which impacts vascular tone and short-term HRV.

Research suggests that changes in BRS and reduced baroreflex function can drastically reduce both total HR Power and LF_P. While it is also claimed that LF_P is representative of BRS and not autonomic tone for HR, this is by no means a universally accepted hypothesis and LF could simply be a represented by a combination of the two (Di Rienzo, Parati, Radaelli, & Castiglioni, 2009; Rahman, Pechnik, Gross, Sewell, & Goldstein, 2011). It is interesting, however, that the percentage of $Power_T$ for LF_P did not differ between the two conditions, suggesting that differences between the two conditions are a product of a process which may influence $Power_T$. Unfortunately, determinants of $Power_T$ are still a largely under investigated area of HRV analysis and more insight into potential determinants is needed. What can be concluded though is the presence of a significant decrease in vagal tone when waking to a call relative to waking controls.

Time Domain Perturbation Discussion

RMSSD and pNN50 values were both significantly lower during waking to a call. This is to be expected as the autonomic response increases HR, decreasing the duration of NN intervals and the overall probability of having these NN intervals differ by more than 50ms. This is similarly seen with RMSSD as the potential values of variability become constricted due to smaller NN intervals. As both of these values are related to PSNS activity, it is no surprise that values when waking for call response were significantly lower than during the control condition. However, neither variable reached cut off points for mortality risk, established from 24-hour recordings (Umetani et al., 1998).

Importantly, literature values for RMSSD tend to support findings from this study, particularly in the control group (Shaffer & Ginsberg, 2017; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). However, these values provide a reasonable range rather than comparative science due to differences in the duration of measurement. Regardless, the data from these comparisons confirms the hypothesis that there is a significant difference in the autonomic wakening response for a call compared to waking organically.

Chapter 6 - Results & Discussion for Amount and Distribution of Sleep

RESULTS: SLEEP QUANTITY AND DISTRIBUTION

Comparisons of total and stage-based between nights with and without a call were done using a one-way ANOVA with further analyses for each variable to determine partial eta squared (η^2) values. Total amount of sleep, measured in minutes, on nights with a call was significantly lower than on nights without a call). Moreover, there was a significant decrease (see Figure 6.1), in REM (η^2=.537), light (η^2=.429), and deep (η^2=.287) sleep in addition to the proportion of total sleep spent in the REM stage (η^2=.570) shown in Figure 6.2. For example, total sleep decreased from 417.13 ± 52.04 minutes to 261.11 ± 61.12 on a night with a call a reduction of over 2.5 hours. Simultaneously, the amount of REM sleep decreased from 109.88 ± 28.47 minutes to 51.44 ± 17.92. Percentages of total sleep spent in REM were also were found to decrease on a night with a call (22.25 ± 3.73% versus 16.44 ± 3.17%) with a large effect size (η^2=.511).

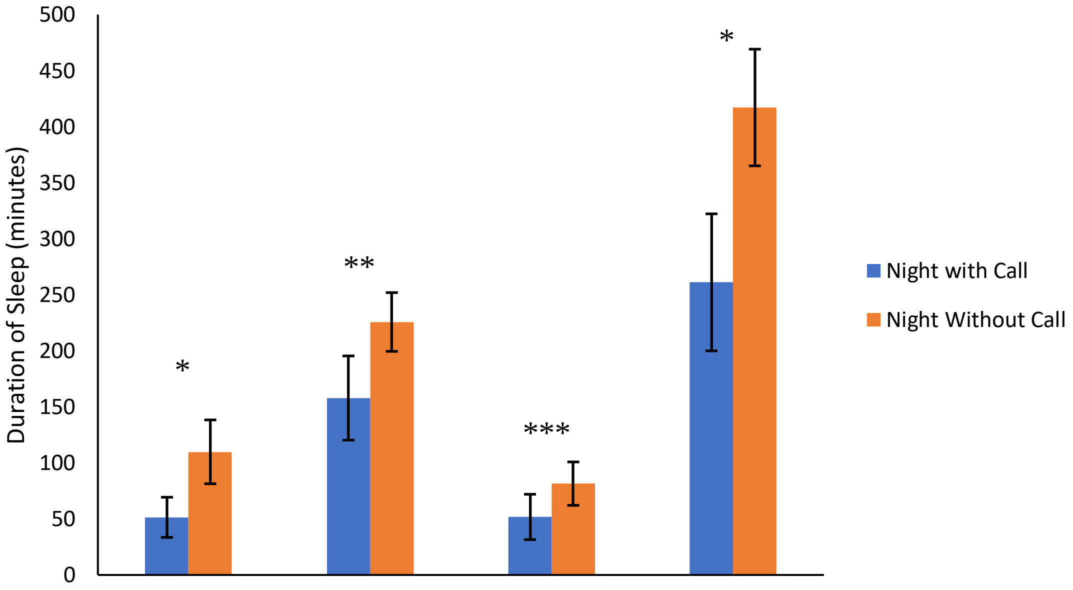

Figure 6.1. Total and stage-based sleep totals on nights with a call compared to nights without a call.

Error bars = 95% CI, *p<.001, **p=.004, ***p=.027

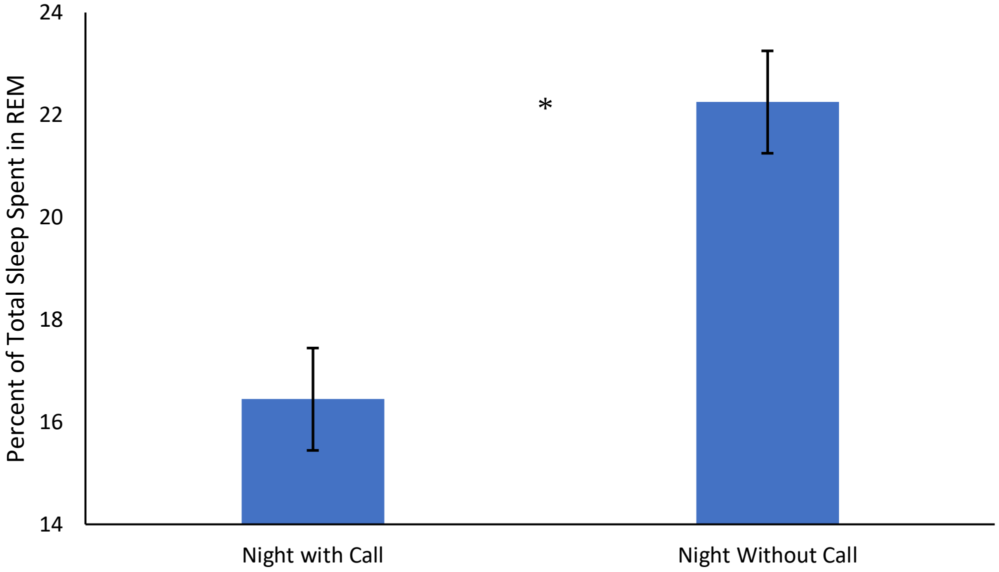

Figure 6.2. Proportion of sleep spent in REM on a night with compared to a night without a call. Error Bars = 95% CI, *p=.009

DISCUSSION: SLEEP QUANTITY AND DISTRIBUTION

Question III: *How much sleep is affected when firefighters are woken by and attend a call and are there any critical insufficiencies?*

On nights with calls, there is statistically significant decreases in the absolute amount of sleep across all measured types and in total duration. Differences were also found for % REM. Reduced total sleep was expected, however the magnitude of overall and stage-specific sleep loss was larger than the hypothesized average deprivation of 60-90 minutes. One significant reason for this is the time of call with respect to the prospective time the firefighter would be waking.

The data shows that following calls after a certain period during the night, firefighters no longer found it worthwhile to return to bed. While the exact time at which this occurs was not determined, it was determined that the transition from sleep to remaining awake could occur as early as 03:15. This time point could be more dynamic than static, depending on factors like fatigue, the persons prospective waking time, duration of call. In contrast, calls before this time provided firefighters with enough time to make returning to bed “worthwhile”. When considering the potential for repetitive night time calls, particularly in busier suburban volunteer departments, these results highlight a potential problematic unhealthy trend if repeatedly encountered.

Total Sleep

For total sleep, popular culture reiterates the importance of getting 7+ hours, 420 minutes, of sleep. Regularly getting fewer than 7 hours is associated with impaired performance and increased errors, and increases risk for various health conditions (Watson et al., 2015). In this population, total sleep was more or less equal to 7 hours on nights without a call at 417.125 ± 52.044 minutes, falling within range of previous research (Elsenbruch, Harnish, & Orr, 1999). However, on nights without a call, the average total amount of sleep was 37.4% less at 261.111 ± 61.116 minutes. This equates to just over 4 hours and 15 minutes, an insufficient amount to reset according to experts. A 1996 meta-analysis on sleep deprivation, less than 5 hours of sleep in a 24-hour period, found that mean performances in said group performed comparable to the 9th percentile of non-sleep deprived subjects on simple motor tasks, demonstrating the impact sleep has on physical acuity, a necessity in both the fire service and in day-to-day life (Pilcher & Huffcutt, 1996).

Sleep

REM sleep is critical for maintaining functional integrity of the prefrontal cortex, a critical area for decision-making and the command center for executive function (J. F. Brunet, McNeil, Doucet, & Forest, 2019; Holanda & de Almondes, 2016). A recent study examining the impact of REM sleep deprivation showed that an average decrease of REM sleep from 22.57% to 14.16% corresponded to increased risk-taking behaviours and impulsivity independent of total sleep, emphasizing the importance of REM sleep (Brunet, McNeil, Doucet, & Forest, 2019). The observed decrease is extremely similar to that of the current study: a decrease from 22.25 ± 3.73% to 16.44 ± 3.17% with a consensus of normal amounts being approximately 25% (Shrivastava, Jung, Saadat, Sirohi, & Crewson, 2014). Similarly, a study of healthy individuals found average REM sleep to be 19.9 ± 1.3% (Elsenbruch et al., 1999). However, the most sizeable difference was between total REM minutes on nights with and without a call. The time of the call matters too with relation to perturbation of REM sleep; the duration of REM periods increase as the night goes on meaning that missing out on your final cycle could deprive a person of up to an hour of REM sleep (della Monica, Johnsen, Atzori, Groeger, & Dijk, 2018).

Total REM minutes during nights with a call were 51.44 ± 17.92 minutes compared to 109.88 ± 28.47 minutes without a call. A consensus on the absolute amount of REM sleep needed proves to be elusive but taking into consideration the 25% rule, an optimal amount of REM sleep to promote healthy cognitive function based on a 7-hour, 420-minute night would be 105 minutes. This is approximately equivalent to the amount of REM sleep experienced on nights without calls but when sleep was interrupted by a call, REM sleep decreased by over 50%. In cases of 24-hour sleep deprivation where REM sleep has been effectively nil, symptoms of psychosis can emerge (Petrovsky et al., 2014).

Light & Deep Sleep

Light sleep is detected with an accuracy of 0.81, highest of the three measured stages and while deep sleep is lowest at 0.49, it tends to be underestimated by 24 minutes per night while light sleep is overestimated by over 30 minutes a night (de Zambotti et al., 2018).

Light sleep, N1+N2 sleep stages, is supposed to comprise 55% of total sleep while deep sleep is typically 20% (Shrivastava et al., 2014). However, in this population, on nights with a call, light sleep and deep sleep comprised 53.55 ± 8.53% and 17.33 ± 6.3% respectively. In contrast, proportions on nights with uninterrupted sleep were 48.63 ± 6.37% and 17.13 ± 3.33% for light and deep sleep. With these comparisons, no statistically significant differences were found.

While proportional percentages did not change, there was a decrease in absolute value, considering the deficit of over 2.5 hours of sleep on nights with a call. Absolute deficits of over 75 minutes for light and a 30-minute deficit in deep sleep exist as a result. Most data surrounding light sleep breaks it into N1 and N2 components which is irreversibly grouped together in FitBit's tracking, making it difficult to determine the direct impact of call response on each stage. It has been reported that N3, or deep sleep, is negatively associated with incident hypertension (Javaheri et al., 2018). That is, deep sleep appears to be associated with reducing and maintaining a reduced blood pressure.

Ultimately, only the absolute amount of light and deep sleep was impacted as a result of call response while percent distribution remained within reasonable levels. This, as mentioned, may be due to the rhythmic cycles of sleep stages throughout the night. However, interruptions that reduce overall sleep repetitively impacts performance, as previously noted.

Chapter 7 - Results & Discussion for Salivary Stress Substances Cortisol and C-Reactive Protein

Salivary Cortisol and CRP Concentration Results

Salivary cortisol (Figure 7.1) exhibited significant increases from baseline following a call (effect size: 1.678), with an average difference of 0.426 ± 0.202 µg/dL. The average differences among the comparison for salivary CRP levels, showed significant differences (p=.034) with a mean difference between pre and post-call of 79.033 ± 85.747 pg/mL. Salivary CRP concentration averages for pre and post-call were 928.781 ± 83.896 pg/mL and 1007.814 ± 155.247 pg/mL respectively with a small effect size of 0.402.

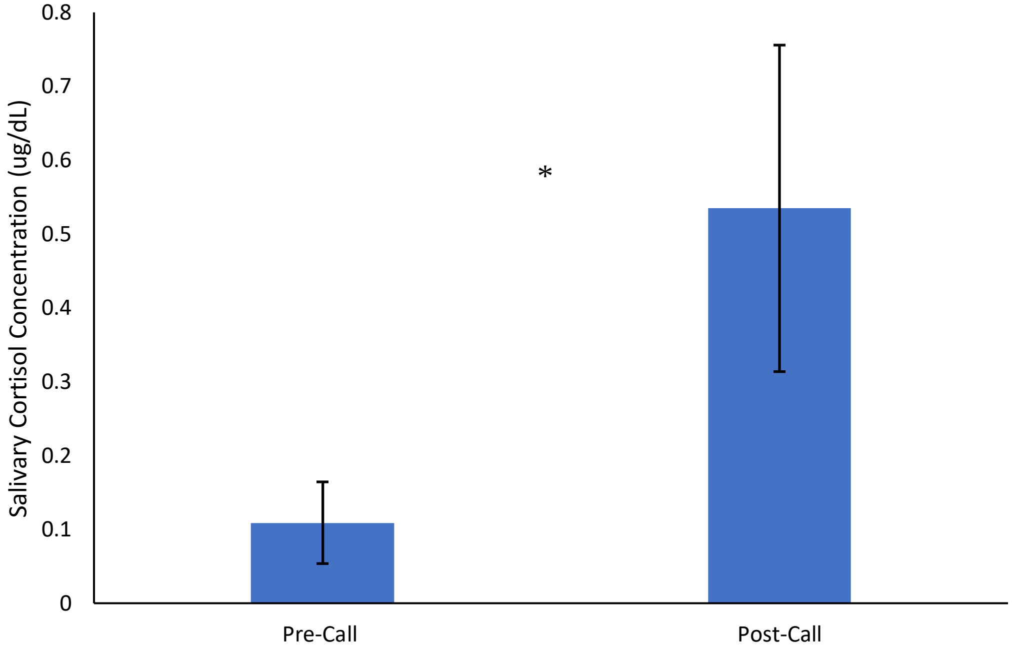

Figure 7.1. Comparison of salivary cortisol concentrations taken within the first five minutes of a call dispatch, and within 15 minutes of returning from the call.

Error Bars = 95% CI, *p=.001

Salivary Cortisol and CRP Concentration Discussion

Question IV: *Do calls initiate a stress response which drastically increase salivary cortisol and c-reactive protein levels?*

It is well known that cortisol levels increase in response to stress in efforts to attenuate inflammation and maintain homeostasis. Salivary cortisol is in fact a reliable measure of biologically active cortisol within the blood stream; 15-20% of cortisol in the blood is unbound and biologically active. Correlations between salivary and free-plasma cortisol are very strong at 0.914 (Duplessis, Rascona, Cullum, & Yeung, 2010). Free-cortisol happens to be the form which readily diffuses into saliva, making saliva analysis a reliable window for observing changes in total cortisol, though this is only confirmed during resting conditions.

In the current study, cortisol levels increased significantly (0.1090 ± 0.0553 µg/dL to 0.5346 ± 0.2210 µg/dL) following attending a call compared to baseline samples, taken within 5 minutes of call dispatching (Bozovic, Racic, & Ivkovic, 2013). This is to be expected, considering the impact of autonomic responses on cortisol and previous research on cortisol responses in firefighters (Smith, DeBlois, Kales, & Horn, 2016). In fact, sleep deprivation, which this study shows is a certainty during night time calls, has been shown to impact cortisol and the inflammatory response (Wolkow, Aisbett, Reynolds, Ferguson, & Main, 2015). Previous research presented at the American College of Sports Medicine regarding thermal stress in firefighter personal protective equipment has shown that cortisol levels can still spike even further than shown in this study, meaning that calls which subject firefighters to frequent high-intensity thermal exposures quite possibly could provide an even greater flux than depicted from this study (Service, Coehoorn, & Stuart-Hill, 2019).

While this comparison demonstrated the significant flux of cortisol in response to call-related stress, one limitation was that no control was done for comparing salivary cortisol concentration and the normal waking response when waking up following nights without a call. This severely limits the ability to draw major conclusions from call response relative to that of waking up without such a stressor. It does still allow for comparison of these values relative to average concentrations reported in the literature. In comparison to peak waking values using similar methodology, (mean ± 95% CI) of 0.739 ± 0.178 μg/dL, post-call cortisol levels were lower, ranging from 0.535 ± 0.221 μg/dL. While this confirms that night time calls disrupt the rhythmicity of cortisol release, it does not definitively say that the wakening response is greater for a call than during a normal wakening response. In the future, it is paramount to add such comparisons to permit conclusions regarding differences in the wakening response.

In terms of reliability of measures, the diurnal pattern of cortisol release results in highest values being observed within approximately 20 minutes of waking up. The time difference between baseline and post-call samples was never less than 45 minutes, meaning cortisol values should have already peaked and been on the decline. This may be a possible reason for the lower values post-call compared to the literature, further emphasizing the need for control comparisons in the future. With respect to collection methods, previous use of oral swabs in other studies has been tumultuous at times, but passive drool provided an abundance of saliva, improving reliability of salivary cortisol values and solidifying it as the method of choice in future studies.

Salivary analysis of c-reactive protein is less established in its usage relative to cortisol but is gaining ground due to links to cardiovascular disease (Luan & Yao, 2018). Correlation between saliva and serum has been reported as 0.72 with nearly a 90% accuracy (Desai & Mathews, 2014). In this experiment, pre-post differences were insignificant, though that is to be expected considering the rate of appearance for CRP. Approximate averages of normal salivary CRP concentrations in healthy populations varies significantly, with studies reporting values ranging from 35-217 pg/mL to as high as 24156 pg/mL (Salimetrics 1st Generation) depending on the assay type/manufacturer (Desai & Mathews, 2014; Ouellet-Morin et al., 2011). The average values from this study lie within the spread of the latter study using Salimetrics, though such a substantial range of averages provides limited insight into the long-term inflammatory effects of a call. Taking samples at 24-28 hours post-call was not done and in future studies this may be beneficial in identifying longer-term inflammatory responses and the peak flux of CRP stemming from the stressor.

Chapter 8 - Conclusion and Future Directions

Conclusion/Answers to Research Questions

The current study investigated firefighters' autonomic responses as a result of call response. RMSSD, pNN50, and LF_P, HF_P and Power_T significantly decreased during call response compared to waking controls, corresponding to a decrease in HRV. These findings also demonstrated a significant reduction in parasympathetic activity. Sympathetic activity increased as HRmax significantly increased in the 15-minutes following call dispatch to values equating to over 86% of one's maximal HR compared to the 15-minutes preceding a call. This is indicative of significant autonomic changes, albeit in the short-term (<75-90 minutes), following a call. Decreases in LF_P and Power_T were observed despite clear increases in sympathetic activity using other measures. This is hypothesized to be due to alterations in RSA or baroreflex function but requires further investigation of both these processes.

When comparing the initial 15 minutes of waking to a call to that of a normal waking pattern, there was found to be a significant difference in every variable using 2-tailed t-tests with the exception of normalized units of LF and HF. Significant decreases were seen in RMSSD, pNN50, and HF_P, indicative of reduced HRV and elevated SNS activity. An important highlight, considering the findings within the literature suggesting the contrary, which was also found in the pre-post comparisons was reduced LF_P, and Power_T. This finding may shed light on the intricacies of cardiovascular control and point to an area to further explore for a potential associative or causative agent that increases cardiovascular risk among firefighters.

Call response significantly reduced the amount of total, REM, light, and deep sleep. On nights with a call, both the overall time spent in REM and percentage of total sleep spend in REM significantly decreased, with a large effect size, to levels which have been known to cause impaired prefrontal cortex function. Future focus on high quality decision-making data with a large sample size can and will be used in the future to investigate the relationship between interrupted sleep and decision-making.

Salivary analyses found that cortisol stress responses of waking and responding to a call were comparable to that of normal waking values presented in the literature, however post-call cortisol response exhibited a significant increase compared to pre-call values. In the future, quantifying a normal waking cortisol response will prove useful to provide context for the call-initiated cortisol flux. Such pre-post differences were also observed for salivary CRP, though the time course stated in the literature for the production and release profile of the substance suggests that call response itself was not a likely cause.

In conclusion, night time call response elicits a stress response of sufficient magnitude to cause significant short-term (15-90 minutes) perturbation of variables related to cardiovascular autonomic control, pathological sleep deprivation, and disruption of diurnal cortisol release and inflammation.

While in some cases, prevention of the response is not feasible, at the very least, these findings can be used to alert firefighters to the impacts of call response as there is limited information in this regard, particularly for firefighters from volunteer and paid-on-call departments. Advising firefighters on the impact insufficient amounts of sleep has is critical to ensuring safety not only on the fire ground but when volunteers proceed to their own workplaces in the morning following a call. A simple example of modifications propelled by this study, with respect to sleep, is the cognizance of fatigue due to a lack of sleep. A firefighter, educated in the potential risks, who is sleep deprived or slept minimally before a call, may be able to limit their exposure to the high-stress zones and tasks at a scene, instead allowing others of similar experience, but with less impeded function, to engage in decision-making. This translates to any high-tension scenario within or outside firefighting.

Future Directions

While the current study has demonstrated a definitive autonomic stress response impacting the cardiovascular system, endocrine responses, and causing significant sleep perturbation, future directions should involve larger sample sizes to compare age and/or experience-related differences in call response in addition to evaluating which type of calls, and possibly the time they are paged out at, appear to elucidate stronger autonomic responses. The rebound effect of HRV among firefighters reinforces their strong resiliency to stressors but firefighters may still benefit from techniques like light physical activity or meditation/breathing exercises post-call in attempts to attenuate the duration of autonomic perturbation and restore vagal tone and Time Domain-based HRV. Knowing autonomic control is altered, monitoring of additional cardiovascular variables would prove beneficial in such a study.

In addition, a further area to explore is the impact of call response among career versus volunteer firefighters to see the impact of call response habituation in shift work and also the impact repetitive exposure may have on magnifying responses. Investigating call response and even resting values over the tenure of a firefighter in a longitudinal study may be beneficial for identifying trends of causative changes. A final possible endeavor would be to compare the response during the day to that of night, however acquiring reliable baseline data, particularly with respect to cardiovascular variables may prove to be a difficult factor to control for. Regardless, the data presented demonstrate an evident need for more insight into how calls, and possibly calls in succession, impact physiological and psychological function.

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Appendix A

University of Victoria | Office of Research Services | Human Research Ethics Board
Administrative Services Building Rm B202 PO Box 1700 STN CSC Victoria BC V8W 2Y2 Canada
T 250-472-4545 | F 250-721-8960 | uvic.ca/research | ethics@uvic.ca

Certificate of Approval

PRINCIPAL INVESTIGATOR: **Lynneth Stuart-Hill**
UVic STATUS: **Faculty**
UVic DEPARTMENT: **EPHE**

ETHICS PROTOCOL NUMBER: **18-100**
Minimal Risk Review - Board members

ORIGINAL APPROVAL DATE: 29-Oct-18
APPROVED ON: 29-Oct-18
APPROVAL EXPIRY DATE: 28-Oct-19

PROJECT TITLE: **Physiological and Psychological Effects of Night Time Call Response in Volunteer Firefighters**

RESEARCH TEAM MEMBER Supervisor: Dr. Lynneth Stuart-Hill, UVic;
Co-Supervisor: Dr. Jodie Gawryluk, UVic;
Masters Student: Thomas Service, UVic

DECLARED PROJECT FUNDING: **Work Safe BC**

CONDITIONS OF APPROVAL

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Modifications
To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.

Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

Dr. Rachael Scarth
Associate Vice-President Research Operations

Certificate Issued On: 29-Oct-18

18-100 Stuart-Hill, Lynneth

Appendix B

Over the last 2 weeks, how often have you been bothered by any of the following problems?	Not at all	Several days	More than half the days	Nearly every day
1 Feeling nervous, anxious or on edge	0	1	2	3
2 Not being able to stop or control worrying	0	1	2	3
3 Worrying too much about different things	0	1	2	3
4 Trouble relaxing	0	1	2	3
5 Being so restless that it is hard to sit still	0	1	2	3
6 Becoming easily annoyed or irritable	0	1	2	3
7 Feeling afraid as if something awful might happen	0	1	2	3

A12 – GAD7 total score ☐

How would you rate your current levels of anxiety today relative to the past two weeks? Please circle

Much lower Slightly Lower The Same Slightly Higher Much Higher

Please describe below, up to 3 ways that you currently use to deal with stress or anxiety. If you do not have any methods, please write “none”. You do not need to fill all three spaces.

1. ______________________________

2. ______________________________

3. ______________________________

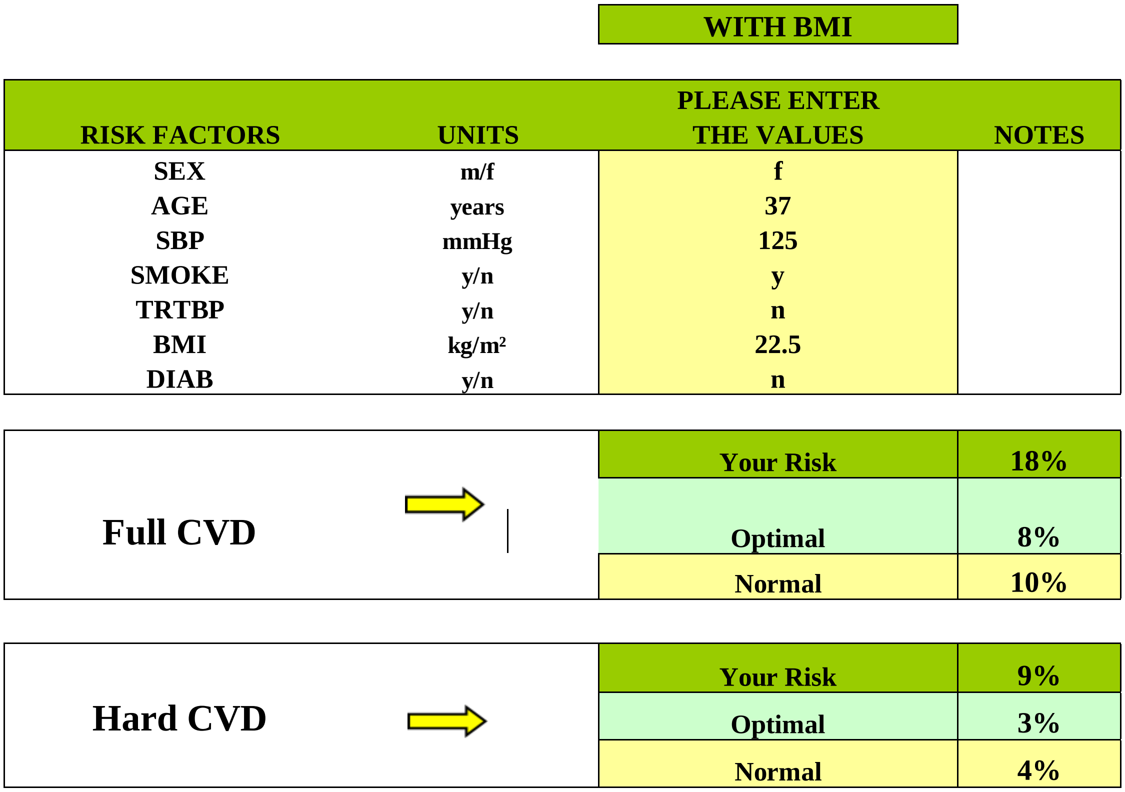
Not included on the survey but used for totaling

Scoring (For Investigator use/viewing only)

0-4	No Anxiety
5-9	Mild Anxiety
10-14	Moderate Anxiety
15-21	Severe Anxiety

Appendix C

30-year risk score for cardiovascular disease



WITH BMI

RISK FACTORS	UNITS	PLEASE ENTER THE VALUES	NOTES
SEX	m/f	f	
AGE	years	37	
SBP	mmHg	125	
SMOKE	y/n	y	
TRTBP	y/n	n	
BMI	kg/m^2	22.5	
DIAB	y/n	n	

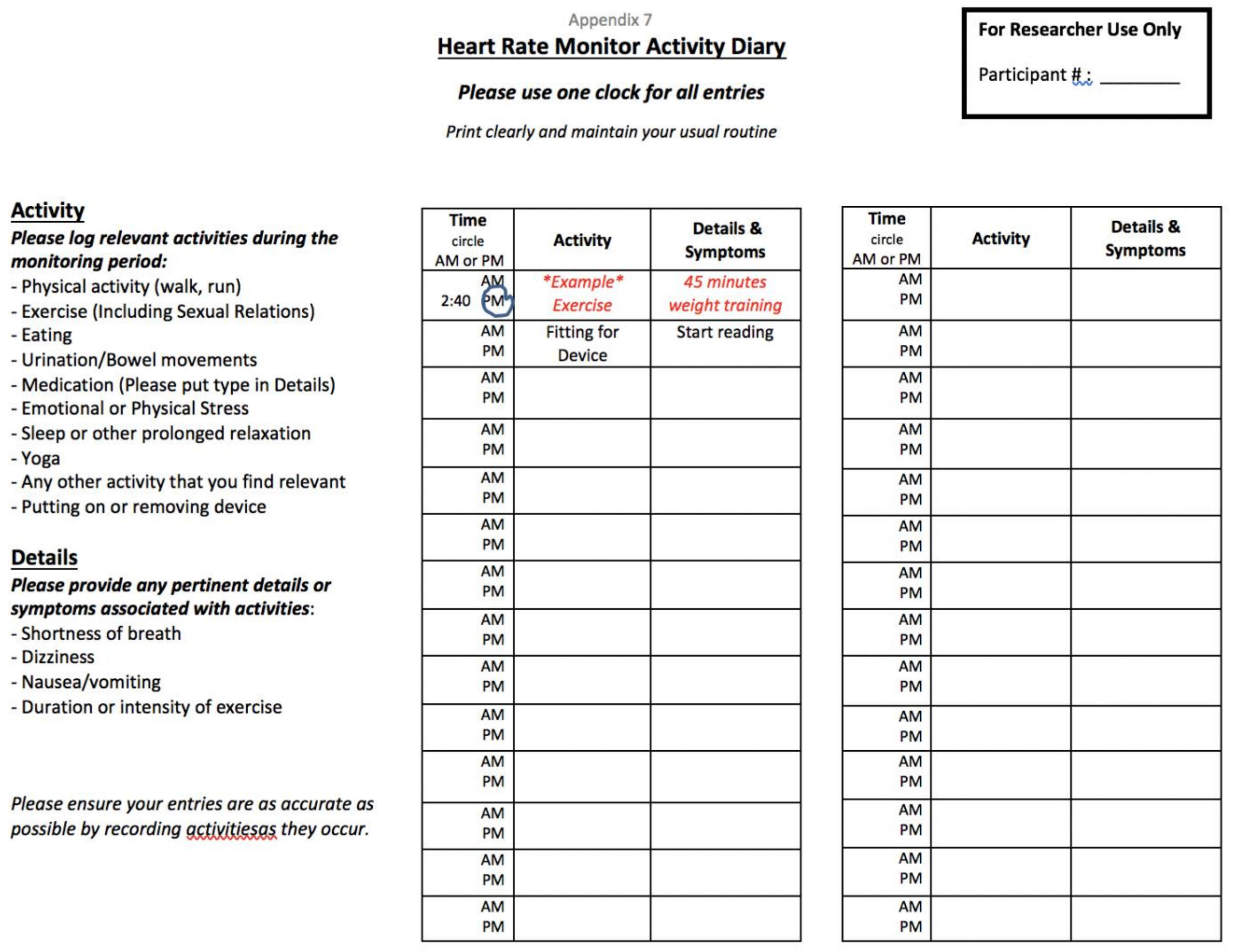
Full CVD	Your Risk	18%
	Optimal	8%
	Normal	10%

Hard CVD	Your Risk	9%
	Optimal	3%
	Normal	4%

Hard CVD: coronary death, myocardial infarction, fatal or non-fatal stroke
Full CVD: hard CVD or coronary insufficiency, angina pectoris, transient ischemic attack, intermittent claudication or congestive heart failure
Calculator prepared by M.J. Pencina and R.B. D'Agostino based on a publication by Pencina et al. in Circulation

Note this is a sample of the table to be used in excel. Subjects will be asked the above questions by investigators and have BP and BMI measurements taken. The information will then be entered into the excel sheet to generate the risk.**

Appendix D



Appendix 7

Heart Rate Monitor Activity Diary

Please use one clock for all entries

Print clearly and maintain your usual routine

For Researcher Use Only

Participant # : ________

Activity

Please log relevant activities during the monitoring period:

- Physical activity (walk, run)
- Exercise (Including Sexual Relations)
- Eating
- Urination/Bowel movements
- Medication (Please put type in Details)
- Emotional or Physical Stress
- Sleep or other prolonged relaxation
- Yoga
- Any other activity that you find relevant
- Putting on or removing device

Details

***Please provide any pertinent details or symptoms associated with activities*:**

- Shortness of breath
- Dizziness
- Nausea/vomiting
- Duration or intensity of exercise

Please ensure your entries are as accurate as possible by recording activitiesas they occur.

Time circle AM or PM	**Activity**	**Details & Symptoms**
2:40 AM [✓ PM]	**Example* Exercise*	*45 minutes weight training*
AM PM	Fitting for Device	Start reading
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		
AM PM		

Time circle AM or PM	**Activity**	**Details & Symptoms**
AM PM		
AM PM		
AM PM		
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AM PM		
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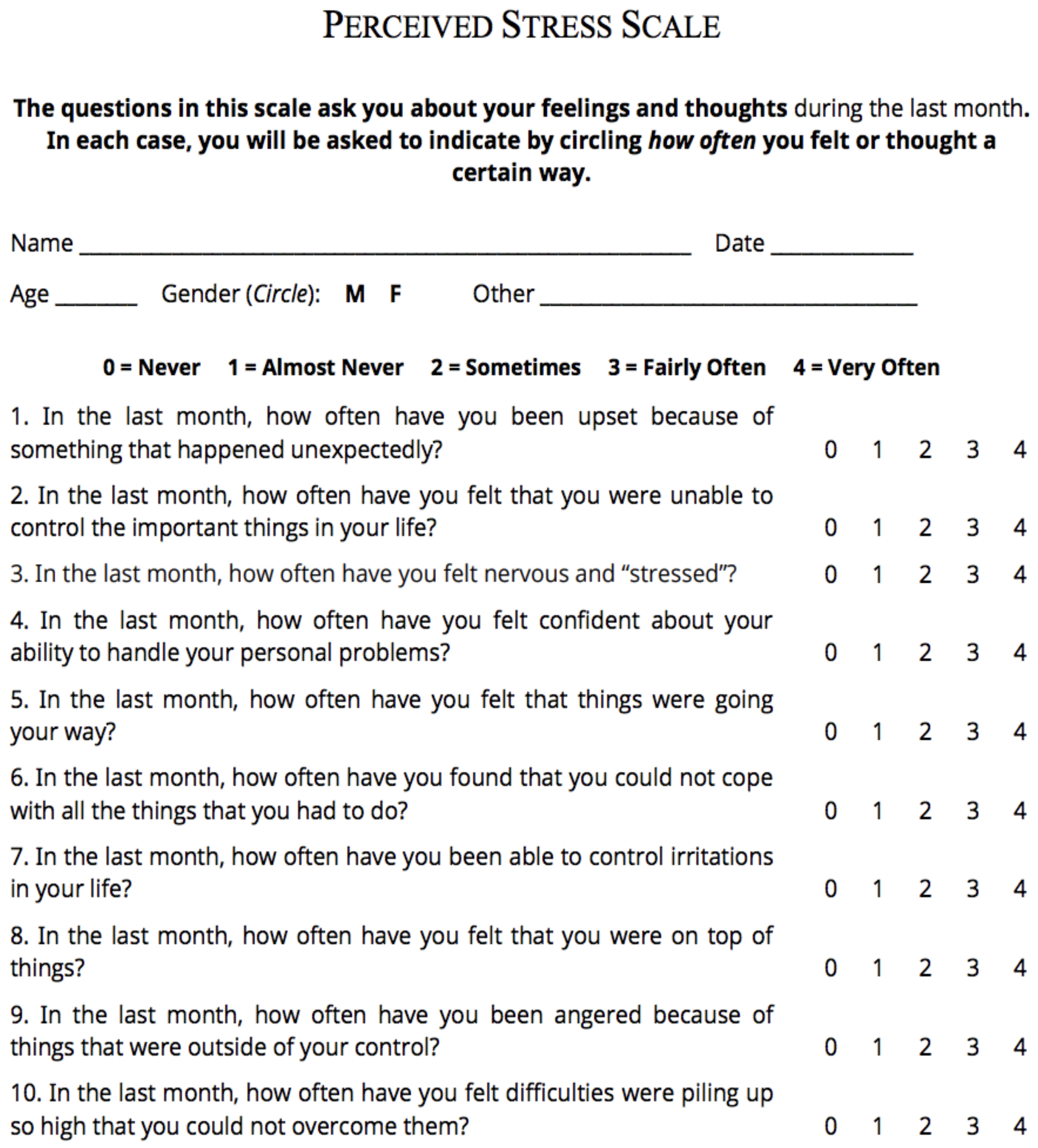
Appendix E



PERCEIVED STRESS SCALE

The questions in this scale ask you about your feelings and thoughts during the last month**.**
In each case, you will be asked to indicate by circling *how often* you felt or thought a certain way.

Name ____ Date __________

Age _______ Gender (*Circle*): **M F** Other ____________________________

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

1. In the last month, how often have you been upset because of something that happened unexpectedly? 0 1 2 3 4
2. In the last month, how often have you felt that you were unable to control the important things in your life? 0 1 2 3 4
3. In the last month, how often have you felt nervous and "stressed"? 0 1 2 3 4
4. In the last month, how often have you felt confident about your ability to handle your personal problems? 0 1 2 3 4
5. In the last month, how often have you felt that things were going your way? 0 1 2 3 4
6. In the last month, how often have you found that you could not cope with all the things that you had to do? 0 1 2 3 4
7. In the last month, how often have you been able to control irritations in your life? 0 1 2 3 4
8. In the last month, how often have you felt that you were on top of things? 0 1 2 3 4
9. In the last month, how often have you been angered because of things that were outside of your control? 0 1 2 3 4
10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them? 0 1 2 3 4

How do you personally handle stress (list any techniques, activities, etc. for stress mitigation that you may use to cope)?

Appendix F

For Researcher Use Only

Participant Number: ___________

For Researcher Use only

PCL-5

Instructions: Below is a list of problems that people sometimes have in response to a very stressful experience. Please read each problem carefully and then circle one of the numbers to the right to indicate how much you have been bothered by that problem in the past month.

In the past month, how much were you bothered by:	**Not at all**	**A little bit**	**Moderately**	**Quite a bit**	**Extremely**
1. Repeated, disturbing, and unwanted memories of the stressful experience?	0	1	2	3	4
2. Repeated, disturbing dreams of the stressful experience?	0	1	2	3	4
3. Suddenly feeling or acting as if the stressful experience were actually happening again (as if you were actually back there reliving it)?	0	1	2	3	4
4. Feeling very upset when something reminded you of the stressful experience?	0	1	2	3	4
5. Having strong physical reactions when something reminded you of the stressful experience (for example, heart pounding, trouble breathing, sweating)?	0	1	2	3	4
6. Avoiding memories, thoughts, or feelings related to the stressful experience?	0	1	2	3	4
7. Avoiding external reminders of the stressful experience (for example, people, places, conversations, activities, objects, or situations)?	0	1	2	3	4
8. Trouble remembering important parts of the stressful experience?	0	1	2	3	4
9. Having strong negative beliefs about yourself, other people, or the world (for example, having thoughts such as: I am bad, there is something seriously wrong with me, no one can be trusted, the world is completely dangerous)?	0	1	2	3	4
10. Blaming yourself or someone else for the stressful experience or what happened after it?	0	1	2	3	4
11. Having strong negative feelings such as fear, horror, anger, guilt, or shame?	0	1	2	3	4
12. Loss of interest in activities that you used to enjoy?	0	1	2	3	4
13. Feeling distant or cut off from other people?	0	1	2	3	4
14. Trouble experiencing positive feelings (for example, being unable to feel happiness or have loving feelings for people close to you)?	0	1	2	3	4
15. Irritable behavior, angry outbursts, or acting aggressively?	0	1	2	3	4
16. Taking too many risks or doing things that could cause you harm?	0	1	2	3	4
17. Being "superalert" or watchful or on guard?	0	1	2	3	4
18. Feeling jumpy or easily startled?	0	1	2	3	4
19. Having difficulty concentrating?	0	1	2	3	4
20. Trouble falling or staying asleep?	0	1	2	3	4

Appendix G

University of Victoria
School of Exercise Science, Physical & Health Education
Center for Occupational and Research Testing

Participant Consent Form

Stress Response and Heart Rate Variability in Volunteer Firefighters During Night Calls

You are being invited to participate in a study titled "Physiological and Psychological Effects of Night Time Call Response in Volunteer Firefighters" being conducted by Dr. Lynneth A. Stuart-Hill, Thomas Service, & Dr. Jodie Gawryluk. Lynneth Stuart-Hill is a faculty member in the School of Exercise Science, Physical and Health Education at the University of Victoria, Thomas Service is a graduate student in Kinesiology, and Jodie Gawryluk is a faculty member of the Department of Psychology and Division of Medical Sciences at the University of Victoria. If you have any questions or concerns about the study, you may contact Mr. Service by phone at [redacted] or via email at [redacted]. Alternatively, you may contact Dr. Stuart-Hill at [redacted] or by emailing [redacted]

The purpose of this study is to examine the effect of wake-up calls and emergency response on the acute cardiovascular response of volunteer firefighters, as measured by blood pressure, heart rate, heart rate variability, and cortisol levels. Individuals working in emergency services (firefighters, paramedics, and police) experience emergency calls during both waking and sleeping hours. These emergency calls demand immediate transitions to an alert state and lead to a rapid stress response. Physiological stress, marked by cortisol level, impacts blood pressure, heart rate, and heart rate variability. Extended cardiovascular stress is detrimental to cardiovascular health. Sudden cardiac death is the number one cause of death for line of duty deaths among firefighters. Understanding the impact of emergency call response- induced stress on the cardiovascular system is essential in developing strategies to reduce detrimental effects. This study will investigate magnitude and persistence of changes in cortisol levels, heart rate, heart rate variability, and blood pressure. Volunteer firefighters irregularly receive emergency wake-up calls at night; the irregularity of calls minimizes the expectation of a call, thereby increasing the stress response. The occupation is considered to be one of the most physically demanding professions causing high physiological stress and high risk of cardiovascular incident. 2016 WorkSafeBC statistics showed that 25% of firefighter deaths were directly attributed to cardiovascular emergencies or cognitive impairments, the only non-cancer fatalities.

Of additional concern is the psychological impact of overnight call response. Many overnight calls come at the expense of rest causing mental fatigue. Critical Incidents are a commonplace in the fire services; roughly 93% of volunteer firefighters will experience critical incident stress in their tenure. Understanding the cognitive and emotional changes that overnight response induces can aid in determining appropriate mitigation techniques while increasing awareness of both the need to debrief and the importance of appropriate "stress releases".

You are being asked to participate in this study because you are a healthy, active volunteer firefighter 19 years of age or older. If you agree to participate in this study, you will be asked to wear a heart rate monitor during the night to measure your cardiovascular response following page-outs. The monitor is comprised of a small, lightweight sensor strapped to your chest by means of an elastic chest belt that is similar to a bra. If you do go on an emergency call during the night, you will also be asked to provide a saliva (spit) sample upon return to the firehall and will participate in a brief decision-making task using a brain-wave sensing headband. Saliva samples will be processed in groups at a University of Victoria Laboratory. Baseline testing will be done for saliva and decision-making when you are being fitted for your devices or when you arrive at the firehall for call response. In addition, a FitBit tracker will be worn to look at perturbations in sleep quality. There will be three brief questionnaires/surveys to complete, possibly multiple times depending on the number of times you wear the monitor, along with basic lifestyle questions and weight, height, and blood pressure calculations. The entirety of the questions and surveys should take roughly fifteen minutes in total and will be done only at the start of the monitoring period.

When you are wearing the heart rate monitor, cardiovascular variables such as heart rate will be monitored continuously so you must wear it at all times.

Participation in this study is designed to minimize inconvenience to you. Brief questionnaires to assess your stress, anxiety, and cardiovascular health will be handed out to aid in explaining data. A further assessment of baseline symptoms for post-traumatic stress disorder will help in evaluating current levels of psychological stress, particularly focusing on the emotional component of stress. It should be noted that the questions asked may have the potential to cause minor emotional discomfort for some people. Throughout this study, you will not be asked to perform any activity outside of what you would normally do on an emergency callout but you will be required to attend all calls within your respective collection period. You are not required to participate in multiple sessions of data collection but you may elect, on your own accord, to participate in up to three recording sessions of consecutive (2 days) nighttime monitoring. Only sessions that contain at least one call will count towards the maximum number of sessions. If you elect to withdraw at any point, you may choose to have your data removed.

Individuals who volunteer to participate in the study will be given information on their own personal responses to calls along with potential methods for managing it, increasing their own safety while on the job. No participants will be “diagnosed” but some universal methods for mitigating stress may be discussed to help participants manage their stress. Incidental findings of concern will result in recommendation to visit a physician and a copy of the data in question will be provided to you to assist the health care provider with an evaluation. The results of this research will contribute to understanding the mechanisms involved in the causation of the higher risk of cardiovascular disease and psychological changes and events in firefighters.

Participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will not be used in analysis or any future analysis. Data will be stored for 5 years before the identifiers and links to identifiers are destroyed. The data will then be kept a further 5 years before destruction.

In order to protect your anonymity, no data will be recorded with your name on it. However, do to the nature of this research you will not be anonymous to the researchers involved and anonymity among peers with respect to your participation in the study cannot be guaranteed due to the parameters of data collection following a call. Your confidentiality and the confidentiality of the data will be protected by assigning an ID number to you, which will be used to code all your data. The data will be stored on a password-protected computer. Both the master list of participants and ID numbers and the password-protected computer will be locked in Office 132 in the McKinnon building.

It is anticipated that the results of this study will be shared with others through presentation both at the firehalls and at conferences and as a publication in a scholarly journal. The Office of the Fire Commissioner and the research team plans to work together to ensure the information is as widely distributed to fellow firefighters as possible. Additionally, data from this study will be used in one or more student theses which will also be posted on the UVic Library website "UVicSpace"

In addition to being able to contact the researchers at the phone numbers and emails at the top of this form, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria [redacted] [redacted]) or via email at [redacted]

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

______________________________	______________________________	________________
Name of Participant	*Signature*	*Date*

There is a potential for the data in this study to be used in separate prospective investigations that would compare volunteer and career firefighters stress responses. Per confidentiality protocols applied to this study, personal identifiers will not be used. The same confidentiality and data storing approaches mentioned above for the current study will apply to this prospective study, (5 years with identifiers/links and a further 5 without before destruction). Signing below indicates that you are providing consent for your collected data to be used in a volunteer-career comparative study, should the opportunity to do so arise.

______________________________	______________________________	________________
Name of Participant	*Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

Appendix H

Salimetrics Salivary Cortisol Assay Protocol:

https://salimetrics.com/wp-content/uploads/2018/03/salivary-cortisol-elisa-kit.pdf

Appendix I

Salimetrics Salivary C-reactive protein Assay Protocol:

https://salimetrics.com/wp-content/uploads/2017/05/c-reactive-protein-saliva-elisa-kit.pdf