Exposure to work-related physical and psychological load in career firefighters at three timepoints over one year

by

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Abstract

Background: Firefighters experience high rates of injury – both physically and to their mental health. Firefighting is a unique context to study the interaction of these factors due to the cyclical nature of the work and interaction of physiological, biomechanical and mental health demands. Measuring these constructs over multiple time-points will provide insights into the cumulative demands associated with firefighting.

Thesis Objectives: To quantify the biomechanical, physiological, and psychological loads during two simulated firefighting tasks, at three time-points over one year and assess variability in these factors over a one-year period, among Thunder Bay Fire Rescue firefighters. The overarching goal of this thesis is to identify prevalent multifactorial firefighting injury risk factors for the development of effective injury prevention strategies.

Methods: Biomechanical load was inferred from measurement of musculoskeletal (MSK) injury risk using the Ovako Working posture Analyzing System (OWAS) applied to video of firefighters performing two simulated firefighting tasks. Physiological load was determined from metrics extracted from the Zephyr BioHarness physiological monitoring device worn by firefighters during both tasks. The Critical Incident Inventory (CII) questionnaire was used to determine critical incident exposure and infer impacts on firefighters' mental health. Data was collected at three time points over one year (November 2017, May 2018, November 2018) to gain insights on cumulative loads associated with firefighting.

Results: Analysis of variance over time indicated that heart rate ($F(2, 48) = 4.685$, p < .05, η_{p2} = 0.163) and working intensity ($F(2, 48) = 5.598$, $p < .05$ $\eta_{p2} = 0.189$) significantly increased from baseline to one-year during the performance of the hose drag task. Heart rate variability significantly increased from baseline to one-year during the performance of the patient transfer

task while lifting at the head ($F(2, 26) = 5.2030$, $p < .05$, $\eta_{p}^{2} = .287$) and lifting at the feet ($F(2, 28) = 3.807$, $p < .05$, $\eta_{p}^{2} = .214$). There were no statistical differences in MSK injury risk over time. Critical incident exposure remained consistently high ($\bar{X}_G = 6.3$ incidents) across all timepoints within the one-year period ($\chi^2(2) = 0.977$, $p = .614$) with highest exposures to incidents involving direct exposure to blood and body fluids as well as incidents involving one or two deaths.

Conclusion: Thunder Bay Fire Rescue firefighters' exposures to biomechanical, physiological, and psychological loads appear to be high and remain high over the one-year period. Musculoskeletal injury risk during task performance is also high and remains unchanged over time. Results indicate that there is a need for ergonomic intervention targeting biomechanical, physiological, and psychological loads associated with firefighting. Future studies should consider the interaction of these factors on firefighter work health including MSK injury risk.

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PREFACE

Note that this thesis is being presented as a "sandwich thesis" where Chapter 1-Introduction provides an overview of the literature related to occupational musculoskeletal injury burden and mechanism and also an overview of firefighting as a context for performing the research. Chapter 2 has been formatted as a scientific paper entitled "*Career firefighters' physiological load and musculoskeletal injury risk during firefighting task performance*" and provides an overview of Thunder Bay Fire Rescue (TBFR) firefighters' exposures to MSK injury risk and physiological load at 3 timepoints over 1 year; it also identifies the variability in these constructs over the 3 timepoints. Chapter 3 has also been formatted as a scientific paper and is entitled, "*Identifying critical incident exposure among Thunder Bay Fire Rescue firefighters*"; this paper provides an assessment of TBFR firefighters' exposure to critical incident exposure over the same three timepoints over one year and also the variability in critical incident exposure over those 3 timepoints where critical incident exposure has been associated with increased risk of post-traumatic stress injury. Chapter 4-Discussion provides an overall review of the study findings and contribution to the existing literature on occupational health in firefighting.

Chapter 1:INTRODUCTION

The following introduction of this thesis provides an overview of the burden of musculoskeletal (MSK) injuries in workplaces, a theoretical overview of a model of causation and the cumulative impacts of loads on MSK injury risk. The introductory paragraph then provides a review of both applied measures of assessing musculoskeletal injury risk relevant to the thesis work. This is followed by a discussion of firefighting as a context for studying MSK injury mechanisms and some of the key factors that contribute to firefighter injury risk. The introduction then provides an overview of the integration of these concepts in an overarching research problem and question.

1.1 Burden of Musculoskeletal Injuries in Workplaces

Occupational injuries impose important physical, psychological and financial burdens at the individual, community, organizational, and public levels (Mock & Cherian, 2008; Workplace Safety and Insurance Board, 2015). The most commonly sustained occupational injury type is MSK injuries (i.e., sprains and strains) (Poplin, Harris, Pollack, Peate, & Burgess, 2012; Walton, Conrad, Furner, & Samo, 2003); which are defined as injuries and disorders affecting the MSK system (i.e., muscles, tendons, ligaments, joints, and nerves). These disorders include repetitive strain injuries, cumulative trauma disorder, MSK injury, and sprains and strains (OHSCO, 2008). Musculoskeletal disorders can be caused or worsened by various workplace hazards and injury risk factors. According to the Ontario Workplace Safety and Insurance Board (WSIB), MSK injuries are the leading type of reported work-related lost-time claims (Workplace Safety and Insurance Board, 2015) and cost Ontario workplaces hundreds of millions of dollars annually as a result of lost productivity and employee absenteeism (Schulte, 2005). These injuries impact the functions of the MSK system including how the body moves (OHSCO, 2008); for example MSK injuries may result in functional movement adaptations, which may then result in further injuries and maladaptive postures that can further increase individual risk of injury (Reiman & Manske, 2011). Physically demanding jobs place higher workloads on workers thereby increasing their risk of sustaining an MSK injury in the workplace (Kumar, 2001). Understanding the specific occupational demands, risk factors (individual and environmental), and workload associated with occupational tasks is integral for quantifying MSK injury risk (Takala et al., 2010). Identifying causation and developing corresponding injury prevention strategies is a relevant and important concern towards mitigating this injury burden and the impacts they have individuals and their society.

1.2 Musculoskeletal Injuries: Risk Factors and Mechanisms

Individual and work-related risk factors that contribute to MSK injury risk are described in the Multivariate Interaction Theory of Musculoskeletal Injury Precipitation (Figure 1) proposed by Kumar (2001). These factors act individually and in combination to impact the MSK system resulting in strain, structural changes, and biomechanical changes to anatomical structures, which further induce pain (Karsh, 2006) and pain impacts function, mobility, and performance of work tasks (Reiman & Manske, 2011).

1.2.1 Multivariate Interaction Theory

Kumar (2001) describes MSK injury causation as a multifactorial interaction between risk factors categorized into genetic, morphological, psychosocial, biomechanical factors. While genetic and morphological factors play a role in occupational injury, they are non-modifiable (Kumar, 2001) and cannot be targeted through ergonomic and / or workplace interventions. Conversely, biomechanical and psychosocial factors are modifiable and are therefore, the focus of many ergonomic injury prevention strategies (Kumar, 2001). As the target of this thesis project is to identify biomechanical, physiological and psychological factors that can be modified towards reducing injury risk exposure among TBFR firefighters, the following section provides a brief review of a.) biomechanical and b.) psychosocial MSK injury risk factors described in the Multivariate Interaction Theory of Musculoskeletal Injury Precipitation (Figure 1) with a view on injury prevention (Kumar, 2001).

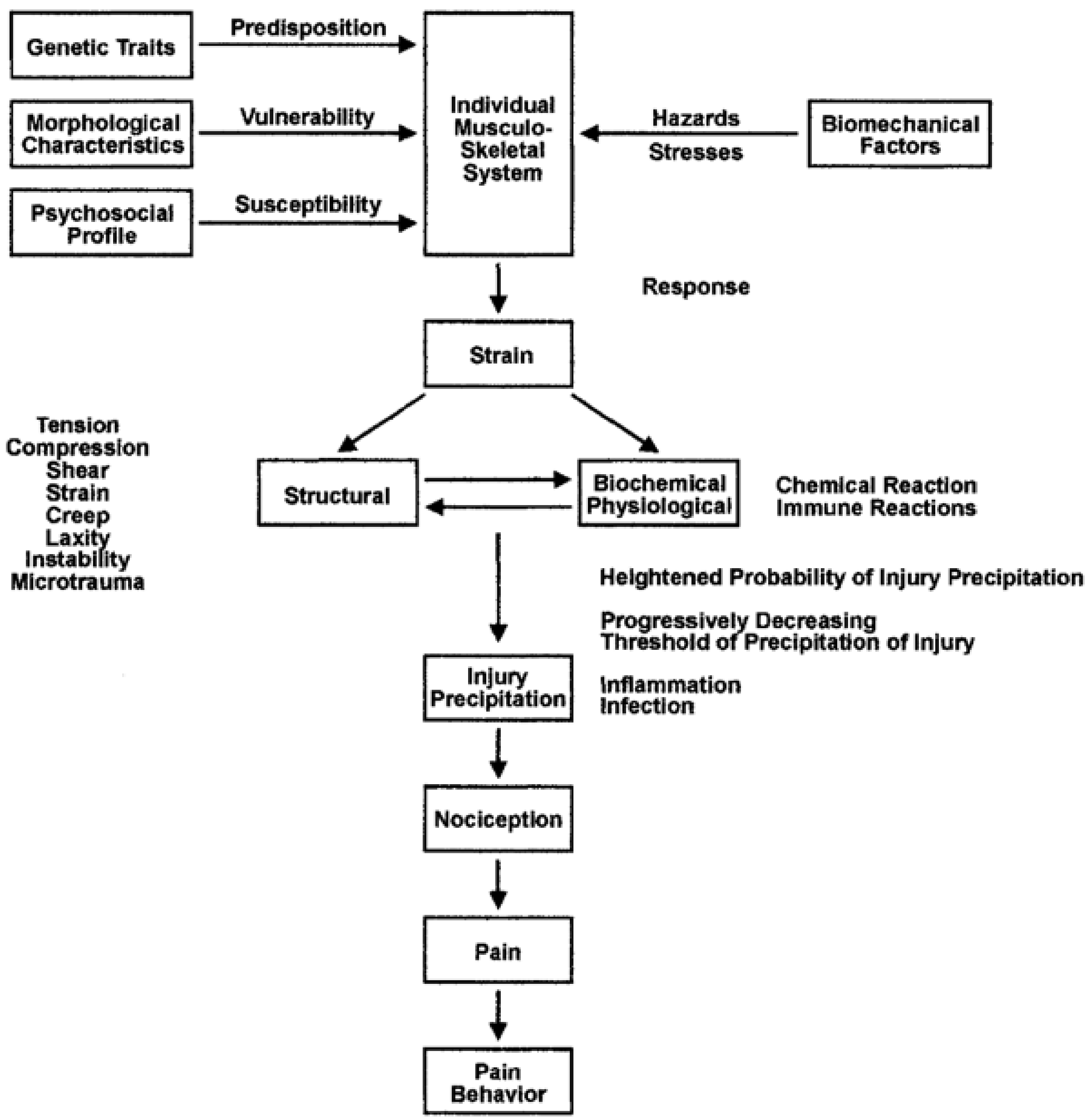

Figure 1.1. Multivariate Interaction Theory of Musculoskeletal Injury Precipitation (Kumar, 2001).

1.2.2 Biomechanical Musculoskeletal Injury Risk Factors

Biomechanical factors resulting in injury precipitation are a result of physical exertions or hazards / stressors (Figure 1) involving a large number of muscles, bones, ligaments, tendons, and joints. These hazards / stressors impact the MSK system which increases strain, impacts issue structure (i.e., tension, compression, shear, strain, etc.) and increases injury risk (see Figure 1). Posture, range of motion, force, repetition, and time are all contributing factors in the classification of physical exertion (Westgaard & Winkel, 1997). Posture is defined as the position of various joints and body segments in space during an activity. Awkward postures are postures that deviate from neutral and are linked to MSK injury (Kumar, 1994). Range of motion is closely linked to posture and describes how much a joint can move. Force can be described as the degree of physical exertion produced by the muscles and/or the amount of pressure placed on the body by the demands of a task. When the amount of force exerted exceeds the tolerance threshold for any particular body system, injury can occur (see Figure 1). Injury risk increases with increased repetition, which is how frequently a task is performed within a unit of time. Time is the duration of which a task is performed with longer durations associated with higher risk of injury. These factors are known to have a direct impact on MSK injury risk and are often targeted in ergonomic injury prevention strategies and as such will be discussed thoroughly in the following sections.

1.2.2.1 Posture and Range of Motion

When assessing MSK injury risk, an important emphasis is placed on measurement of working postures during task performance, as they are an integral to MSK health (Vieira & Kumar, 2004). Working postures are influenced by movements such as reaching, bending, and pulling. Performing these movements with joints closer to their end range of motion results in awkward postures. MSK injury risk is heightened by tasks performed in awkward postures. Awkward postures are classified based on the principle that the farther a joint moves away from neutral there is an associated increased risk of injury to the surrounding tissues (Keyserling, Brouwer, & Silverstein, 1992). Performing tasks in extreme ranges of motion places the joint, its components, and surrounding tissue (i.e., muscle, tendon, bone) at a mechanical and physiological disadvantage as a result of increased moments (Kumar, 2001). Neutral posture is achieved when a joint is operating near the middle of its range of motion and is deemed to be the healthiest for MSK systems as it imposes the lowest risk of injury. Anthropometric measurements, the nature of the task, workstation and tool design are all factors that influence posture (Vieira & Kumar, 2004). While anthropometric characteristics cannot be altered, modification of the task can mitigate injury risk. The duration of time, the frequency, and amount of force exerted or sustained when a worker is in an awkward posture are all factors to consider when assessing the risk imposed by an awkward posture (Vieira & Kumar, 2004). While each factor is known to impact MSK injury risk, the cumulative loading of risk factors substantially increases injury risk. For example, a task requiring repetitive bending while carrying a heavy load is likely to cause an injury sooner/ more severely than the same task performed without a load.

1.2.2.2 Force

In physics, force is defined as the interaction between an object's mass and the acceleration with which it moves to cause the object to be pushed or pulled in a particular direction (Hall, 2018). Force as it relates to risk factors associated with MSK injuries is defined as the amount of effort or physical exertion required of the muscles to perform the demands of a job. Performance of work tasks requires a degree of exertion, however when the level of force exerted exceeds the tolerance of a muscle or surrounding tissue (e.g., tendons, joints, bone, soft tissue), damage to those structures is likely to occur (Kumar, 1994). Injury can be caused by a single exertion or from repeated loading of the muscles and tissue. The physical exertion of force is a well-known risk factor associated with MSK injury (Vieira & Kumar, 2004). Physical exertion has been defined as forces produced by bodily systems to meet the demands of a task (Westgaard & Winkel, 1997). Task performance strategies require muscle recruitment and generation of force to meet the demands of completing that task; provided task demands remain lower than the tissue tolerances associated with the task, MSK injury is unlikely to occur. However, when the amount of force required to perform a task exceeds that of the system or tissue's tolerance, damage to the muscles, tendons, and other soft tissues is likely to occur (Kumar, 2001). While this risk of injury is heightened with repeated exertions, held for longer durations, or while the body is in an awkward posture, injury can also occur from a single high singular exertion of external force (Kumar, 1994).

1.2.2.3 Repetition

Repetition in context of MSK injury is defined as the repeated use of same body segments, muscles, or joints with limited rest periods during occupational task performance. Repetition places high stresses on body structures through repeated loadings of muscles and tissues. Repetition requires muscles to generate forces repeatedly often with little time for recovery or rest. These repeated loadings with limited recovery increases the risk of injury through mechanisms of fatigue and tissue damage that ultimately leads to pain and discomfort (Kumar, 1994). Risk of injury is further heightened with repeated application of high forces and awkward postures.

1.2.2.4 Time

Time is also a risk factor frequently considered with the aforementioned MSK injury risk factors and refers to the length of time an awkward posture, force exertion is held (static) and the duration of time a repeated task is performed (dynamic). The primary concept is that tasks performed with longer durations place individuals at higher risk of injury (Westgaard & Winkel, 1997).

1.2.2.5 Overexertion

The interaction and cumulative exposures to the aforementioned biomechanical factors can result in overexertion. Overexertion is a manifestation of the integration of these MSK injury risk factors. The exertion of force, repeatedly and/or for long durations of time is the primary contributing factor that defines overexertion as a key risk factor associated with MSK injury (Figure 2). Overexertion is defined as a level of physical exertion (of force) that exceeds a system's tolerance limits (Kumar, 2001). As described by the model of overexertion proposed by Kumar (1994), the extent of motion, strength of exertion, and exposure time (surrogate measure of physiological fatigue) are exertions that play a role in overexertion mediated MSK injury risk. So long as the extent of these exertions remains at or below the preferred work limit, risk is neutral. As the amount of exertion increases towards the constant work level and above, job-mediated risk progressively increases (Kumar, 1994).

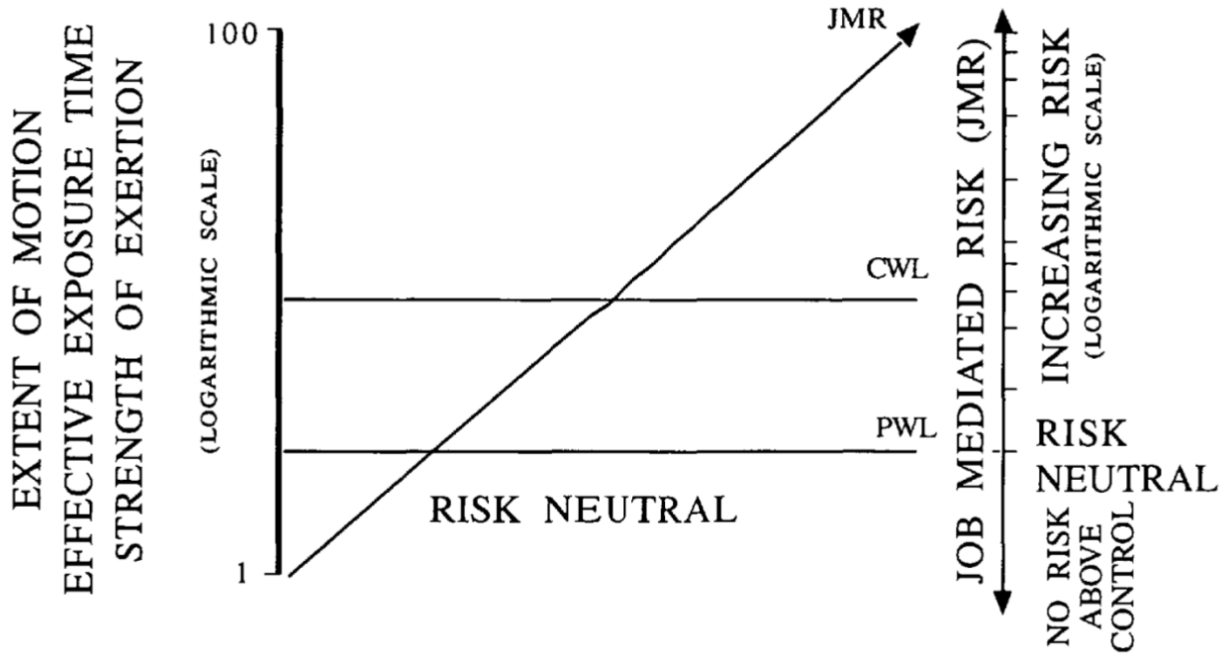

Figure 1.2. Conceptual relationship between increasing strength of exertion, effective time exposure, and extent of motion above preferred work level (PWL) and job-mediated risk (JMR) of injury. (CWL = constant work level.) (Kumar, 1994).

In summary, force, repetition, and time and their impacts on overexertion are well established MSK injury risk factors that have been well characterized in the literature. These risk factors can often be modified in workplaces and are commonly targeted in ergonomic injury prevention strategies. Furthermore, identifying measures associated with force, repetition and time are integrated in both ergonomic assessments and applied research towards developing targeted injury prevention strategies. Consequently, the first paper in this thesis utilizes these principles in assessing MSK injury risk while firefighters perform two simulated firefighting tasks; details regarding this approach are provided in a later section in the thesis.

1.2.3 Fatigue and Physiological Response as a Risk Factor for Musculoskeletal Injury

Fatigue is a complex construct; consequently, an accurate definition must first be established to distinguish fatigue from sleepiness and identify its physical and mental manifestations (Shen, Barbera, & Shapiro, 2006). Shen, Barbera, and Shapiro (2006) have defined fatigue as "an overwhelming sense of tiredness, lack of energy and a feeling of exhaustion, associated with impaired physical and cognitive functioning; which is distinct from symptoms of depression, which include a lack of self-esteem, sadness and despair or hopelessness”. Fatigue is multidimensional in that it can be acute or chronic; physiological or psychological; and central or peripheral (Shen et al., 2006). Acute fatigue is a short-lived, adaptive response to a single cause or stressor; mediated through the sympathetic nervous system. Once the stressor is removed, acute fatigue is quickly alleviated by activation of the parasympathetic nervous system, initiating rest and recovery (Kaikkonen, Lindholm, & Lusa, 2017). Conversely, chronic fatigue persists over a longer duration of time and is a result of cumulative stressors and chronic activation of the sympathetic nervous system (Shen et al., 2006). Chronic fatigue is maladaptive with no known function (Aaronson et al., 1999) and may suppress the parasympathetic nervous system (Kaikkonen et al., 2017). While acute fatigue, characterized by a rapid onset and short duration, is viewed as normal, and part of the regular function of the body; chronic fatigue is deemed as pathological and detrimental to one's quality of life (Aaronson et al., 1999).

In addition to temporal characteristics, fatigue can be characterized by physiological and psychological constructs. Physiological fatigue is a result of excessive energy expenditure that causes a decrease in maximal force production capacity, while psychological fatigue is a result of emotional stress causing a feeling (subjective) of weariness (K. A. Lee, Hicks, & Nino-Murcia, 1991).

Finally, fatigue may be a result of central or peripheral malfunctions. Central causes of fatigue are due to impaired function of the central nervous system, such as faulty transmission between the central and peripheral nervous systems or issues with specific regions of the central nervous system (e.g., hypothalamic region) (Aaronson et al., 1999). Peripheral fatigue is explained by the impaired functioning of the peripheral nervous system that is causing the manifestation of fatigue (Shen et al., 2006). An example of peripheral fatigue may be diminished neuromuscular functioning (Aaronson et al., 1999). Central fatigue focuses on psychological factors, and peripheral fatigue is associated with physical etiological factors of fatigue (O'Dell, Meighen, & Riggs, 1996). Firefighters' high exposure to physical and psychological loads (Guidotti, 1992) can result in cumulative overload effects. The cumulative effects of these functional demands have a demonstrated impact on various biophysical measures, including a decrease in heart rate variability (HRV); which has been demonstrated to be a manifestation, if not presence, of central fatigue (Shaffer, McCraty, & Zerr, 2014).

1.2.4 Psychosocial Factors and Musculoskeletal Injury

There is emerging evidence in the literature that a number of psychosocial factors impact worker health, and more specifically, work-related MSK injury (Stock et al., 2018; Togo & Takahashi, 2009). Psychosocial factors are environmental influences in the workplace that support or inhibit employees in fostering a healthy work environment (Stock et al., 2018). These factors play an important role in the mental health of employees. Psychosocial factors are also known to play a role in MSK injury causation (Kumar, 2001). Psychological stresses stem from many different factors. Current research has identified 13 psychosocial hazards. These psychosocial hazards are: Psychological Support, Organizational Culture, Clear Leadership & Expectations, Civility & Respect, Psychological Competencies & Requirements, Growth & Development, Recognition & Reward, Involvement & Influence, Workload Management, Engagement, Balance, Psychological Protection, Protection of Physical Safety (Samra, Gilbert, Shain, & Bilsker, 2009). Research supporting the link between the presence of negative psychosocial hazards and an increased risk of MSK injuries have been noted (Treaster & Burr, 2004). For example, increased job dissatisfaction, increased anxiety and depression, and fatigue have been found to be associated with the increased experience of low-back pain (Biering-Sørensen, 1984; Frymoyer, Rosen, Clements, & Pope, 1985; Vällfors, 1985). The psychological stressors listed above encompass the common workplace psychological factors in addition to many occupation-specific psychological stressors. The impacts of certain job-specific stressors not encompassed by the typical psychosocial risk factors have not been thoroughly explored. Therefore, quantification of such psychological exposures is important for further exploration of their impacts on worker health.

1.3 Impacts of Physical and Psychological Work Demand Exposures Over Time

The effect of cumulative workload on physical and mental systems has been previously examined (Kumar, 2001; Zhang & Yu, 2010) and the Cumulative Load Theory attempts to explain the impact of cumulative work on MSK injury risk (2001). For physical systems, the Cumulative Load Theory highlights and explains how repetition of loading on biological tissues impacts injury mechanisms. Biological tissue has the capacity to repair itself after physical loading and stresses; however, if these loadings are repeated, with insufficient recovery time, tissues begin to deteriorate (Kumar, 2001). This can result in permanent changes to tissues, reducing the load-bearing capacity of tissues and structures (Kumar, 2001). These changes result in a reduced tolerance to future biomechanical stressors, increasing future risk of further injury (Kumar, 2001).

For psychological systems, mental capacity can also be affected by cumulative overload and is considered in the Cumulative Load Theory. Continuous cognitive activity, and repeated exposure to mentally demanding tasks, and/or psychological stressors over a period of time has been known to have adverse effects on psychological functioning; such as emotional control (i.e., expression of anger, depression, etc.) (Monnier, Cameron, Hobfoll, & Gribble, 2002; Zhang & Yu, 2010). Furthermore, psychological functioning, such as depression, anxiety, and emotional stress, have been found to be strongly associated with the prevalence of fatigue (Kaikkonen et al., 2017). Fatigue in these studies was characterized by reduced heart rate variability and experiences of weariness, reduced alertness, and reduced performance (Chen, 1986; Zhang & Yu, 2010). These workers experienced decreased workplace productivity, decreased health, and increased accidents (Zhang & Yu, 2010). However, much of this work is based on short term studies that have yet to identify the cumulative loads associated with applied or actual work environments on individual injury risk. Quantifying risk factors at repeated measures across time would improve insights on the impact of cumulative loads on MSK injury risk and psychological health.

1.4 Assessing Risk Factors for Musculoskeletal Injuries

Musculoskeletal injuries result in pain that ultimately impacts mobility and function. This impacts work performance by limiting workplace productivity and increasing absenteeism, lost time, injury and compensations claims (OHSCO, 2008), thus increasing the financial burden on workplaces and the larger community. Understanding the factors that contribute to these injuries in the workplace is important for the development of mitigation strategies to keep workers safe and healthy. The following sections provide a review of approaches to measure biomechanical injury risk factors.

1.4.1 Assessment of Biomechanical Risk Factors

There are various methods and tools used to assess the aforementioned biomechanical injury risk factors. Assessment results are then used to determine the risk of injury that is likely to occur as a result of the assessed workplace factors associated with various occupational tasks. Factors considered in biomechanical risk assessment include posture, force, repetition, and time. The "gold standard" for measuring biomechanical injury risk factors is three-dimensional motion capture to enable kinematic measures integrated with kinetic measures (Maykut, Taylor-Haas, Paterno, DiCesare, & Ford, 2015; Schurr, Marshall, Resch, & Saliba, 2017). Kinematic and kinetic measures provide measurement of postures and forces respectively. Kinematic analysis involves the measurement of motion to better understand functional performance (Ann & Chao, 1984). Kinematic analysis can be performed using video recordings imported into movement analysis software that allow for measurement of the angular displacement of body segments (Nunes, Moreira, & Tavares, 2012).

While the lab-based measures discussed above are the gold standard for measuring postures and forces, they have limited field applications, because of financial and spatial constraints (Maykut et al., 2015). Three-dimensional motion capture systems, force platforms, and EMG sensors are costly and complex to set up and use. In addition, they require certain spatial parameters and conditions, making them less applicable for field use. These limitations make theoretical measures of posture and force often inaccessible. In order to address some of these limitations, there are a number of observational risk assessment tools developed for applied use in various occupational contexts that have been developed based on the theoretical model described in Figure 1. These tools assess workload, workplace hazards, and injury risk factors in occupational settings and have been adapted for implementation by professionals who conduct injury risk assessments (i.e., ergonomists, health and safety professionals, kinesiologists, occupational therapists). Risk stratification as determined by using observational MSK injury risk assessment tools are used to inform the development of injury prevention strategies

(OHSCO, 2008). (Takala et al., 2010). One of the most commonly used observational MSK injury risk assessment tool is the The Ovako Working Posture Analysis System (OWAS).

1.4.1.1 The Ovako Working Posture Analysis System (OWAS)

This System (OWAS) assesses posture and load associated with work tasks to determine MSK injury risk and need for ergonomic change associated with risk levels (Takala et al., 2010). The OWAS is an observational injury risk assessment tool used by practitioners (e.g., kinesiologists, ergonomists, occupational therapists) in various workplace settings to describe workloads and MSK injury risk. The OWAS was developed to describe postures and workloads associated with occupational tasks (Takala et al., 2010). The tool encompasses biomechanical risk factors such as posture and load to determine risk for MSK injury and the urgency of ergonomic change required to reduce MSK injury risk. Assessment of injury risk using OWAS includes observation of common working postures for the spine (four postures), upper extremities (three postures) and lower extremities (seven postures) in addition to the weight of the load handled (three categories) while performing working postures. Determination of the posture of each of the body regions allows for the classification of whole-body posture into one of four action categories and their associated need for ergonomic change. The action categories are as follows:

Action Category 1: Normal postures, no special attention required;

Action Category 2: Postures must be examined during the next scheduled check of work demands;

Action Category 3: Postures require examination within a short period of time;

Action Category 4: Postures require urgent re-examination and modification (Kee & Karwowski, 2007; Takala et al., 2010).

These action categories have been determined based on the interaction of biomechanical injury risk factors previously described (i.e., force, repetition, posture, time) associated with working postures (Mattila, Karwowski, & Vilkki, 1993).

1.4.2 Assessment of Physiological Load and Fatigue as Injury Risk Factors

Higher physiological exertions are known to result in MSK injury by way of physiological fatigue (Kong, Suyama, & Hostler, 2013). Heart rate is a primary measure of physiological load. Heart rate describes how hard the cardiovascular system is working to meet the demands of a task. In order to better understand physiological load, heart rate is often observed as a percentage of one's estimated maximum heart rate. This contextualizes how 'hard' an individual is working, relative to their maximal capacity (Tanaka, Monahan, & Seals, 2001).

1.5 Stress Response, Heart Rate Variability, and Fatigue

Stress is defined by Tsigos and Chrousos (2002) as "...a state of disharmony or threatened homeostasis". The stress response is initiated by environmental factors, which relay a perceived threat to an individual's safety. This perceived threat is usually the result of demands being perceived to exceed the individual's resources and therefore endangering their well-being (Lazarus & Folkman, 1984). A stressor may be physical or psychological in nature (Tsigos & Chrousos, 2002). Regardless of the stressor, when a threat is perceived, a message is sent, via neural pathways, to a central control system: the hypothalamus (Tsigos & Chrousos, 2002). The hypothalamus then relays a signal to the hypothalamus-pituitary-adrenal (HPA) axis and to the sympathetic nervous system (via the autonomic nervous system (ANS)) (Tsigos & Chrousos, 2002). The ANS maintains homeostasis of the autonomic (involuntary) bodily functions; through the sympathetic and parasympathetic nervous pathways (Shaffer et al., 2014). When a stressor is experienced, the sympathetic branch of the ANS is activated along with the HPA axis (Thoma et al., 2013). The HPA axis and the sympathetic nervous system (SNS) then elicit various psychological and physiological processes that up- and down-regulate many pathways that allow the person to respond to the demand (e.g. increase blood flow to muscles so they can run away; Thoma et al., 2013; Tsigos & Chrousos, 2002). Some of these processes include: an increase in heart and respiratory rate, increased bronchodilation, increased sweat gland activation, dilation of the pupils, reduced gut motility and urinary system output and function (Porges, 1992). The SNS is best known for mediating the neuronal and hormonal stress response commonly known as the fight-or-flight response. This response is also known as sympathoadrenal response of the body, as it activates the secretion of adrenaline (epinephrine) and to a lesser extent noradrenaline (norepinephrine) from the adrenal gland (Porges, 1992; Tsigos & Chrousos, 2002). Therefore, this response acts primarily on the cardiovascular system. Due to this, another feature of an activated SNS is a decrease in heart rate variability (HRV) (Shaffer et al., 2014).

Heart rate variability is a measure used to observe the interbeat interval (IBI) of consecutive heartbeats. This measure provides information on the fluctuation in autonomic nervous system (ANS) activity, providing insights on the stress response. Normal HRV values (measured as standard deviation of normal-normal beats) are typically above 100ms (M = 141, SD = 39; Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996) with HRV values below 100ms related to poor health outcomes (Kleiger, Miller, Bigger, & Moss, 1987).

Decreases in HRV is a typical finding during the experience of stress (Kaikkonen et al., 2017) and chronic, reduced HRV is considered a marker of prolonged stress and poor health in working populations (Thayer, Åhs, Fredrikson, Sollers, & Wager, 2012; Togo & Takahashi, 2009). As formerly mentioned, the autonomic nervous system has two divisions: the sympathetic and parasympathetic. While the SNS is best known as ‘fight-or-flight’, the parasympathetic nervous system is conversely best known as ‘rest-and-relaxation’ (Salahuddin, Cho, Jeong, & Kim, 2007). As such, the various cardiovascular, respiratory, gastrointestinal, renal, and endocrine functions are also up- or down-regulated by the parasympathetic system; but typically with the opposite stimulatory affect as the SNS (Gilbey & Michael Spyer, 1993). For example, during the experience of stress, the vagal and sacral pathways of the parasympathetic nervous system (PSNS) are also activated to mediate cardiac and gut responses respectively (Porges, 1992; Stratakis, Gold, & Chrousos, 1995). The PSNS also regulates cardiac activity via the vagal pathway down-regulating heart rate and increasing HRV, returning the body to homeostasis (Porges, 1992).

The experience of stress is a multi-faceted phenomenon that has cognitive, emotional, and physical origins. These experiences are closely linked with various physiological and psychological processes. Since the sympathetic and parasympathetic pathways regulate HRV, there is good evidence that observation of HRV is an effective method for assessment of workplace stress (Aaronson et al., 1999), mental health, and depression (Tran, Wijesuriya, Tarvainen, Karjalainen, & Craig, 2009) including post-traumatic stress disorder (Thayer et al., 2012). As such, regular HRV measures in individuals are also being used as indicators of overall health risks associated with stress and more specifically, work-related stress (Togo & Takahashi, 2009). Currently, the most accurate method for measuring HRV is using an electrocardiogram (ECG). This is done through the measurement of time in milliseconds between the production of R waves, within the QRS complexes, of consecutive heartbeats displayed on an ECG. Measures of HRV exclude abnormal or ectopic beats and consider only normal sinus beats. Once that data is gathered, HRV can be further assessed using different analytical approaches within frequency domain and time domain methods (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). A time-domain analysis was conducted for the purposes of this thesis, however, the following sections provide a brief overview of both methods.

Frequency domain analysis of HRV data provides information on the amplitude, expressed as a power density signal, in addition to the frequency of various rhythms within an HRV waveform (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). The frequency domain is advantageous compared to time domain, as it isolates unwanted frequency from the signal and provides detailed information on the activity of various physiological mechanisms that innervate and affect the heart's rhythm. This is done using filtering techniques to extract high-frequency (HF), low-frequency (LF), very-low-frequency (VLF), and ultra-low-frequency (ULF) bands from HRV data (Task Force of The European Society of Cardiology and the North American Society for Pacing and Electrophysiology, 1996). Each band requires various recording periods to determine the associated measurement outcome associated with it. Each band provides information on the activity of various branches of the nervous system and their innervation of cardiac and neural systems (Shaffer & Ginsberg, 2017).

Time domain measures, on the other hand, use mean, normal-to-normal (NN) intervals in conjunction with statistical measures for analysis of HRV data. The variance in measures of interbeat intervals throughout the recording is quantified using various statistical analyses. Specifically, the standard deviation of the NN intervals provides a value called the SDNN which are commonly used to predict morbidity and mortality (Kleiger et al., 1987). Additionally, SDNN provides insights on activity of the sympathetic and parasympathetic nervous systems indicating whether an individual is “stressed” or “relaxed” (Salahuddin et al., 2007; Thayer et al., 2012). Measures of SDNN may also provide information on inappropriate SNS activation/ malfunctioning of the SNS (Shaffer et al., 2014).

Although time-domain measures provide less overall information compared to frequency-domain analysis, they are more often used in the literature because they are more feasible to obtain and analyses as more devices are capable of extracting this data. Therefore, the ease of obtaining HRV data comes at the cost of losing detailed information on the activity of the autonomic system and specific physiological control systems, unless appropriate filtering techniques are implemented (Shaffer et al., 2014). However, time domain measures can provide reliable information on general SNS activity which has been shown to beneficial for detecting fatigue and understanding other health outcomes (Shaffer & Ginsberg, 2017). Measures of SDNN are typically recorded for a minimum of 5 minutes, however there is supporting evidence for the use of ultra-short-term periods of 10 seconds, 30 seconds, and 60 seconds (Baek, Cho, Cho, & Woo, 2015; Esco & Flatt, 2014; Salahuddin et al., 2007). High SDNN values are indicative of one’s adaptability to external challenges and stressors while a lower SDNN is associated with higher risk of morbidity and adverse health outcomes (DeGiorgio et al., 2010; Shaffer et al., 2014).

As a function of its ability to reflect ANS activation, HRV has been identified as a promising method for detecting the presence of chronic fatigue in working individuals (Tran et al., 2009). As such, for the purpose of this thesis, SDNN measures were used to determine the balance of the ANS and prevalence of fatigue. The time-domain measure was used to estimate the effects of vagal activity on HRV (Kleiger et al., 1987; Shaffer et al., 2014).

1.5.1 Assessment of Psychological Risk Factors

In addition to the biomechanical and physiological responses associated with work demands, psychological demands are also a key factor to consider in developing strategies to improve worker health.

For the purpose of this thesis, a key factor that contributes to firefighters' mental health is their individual exposure to critical events (Monnier et al., 2002). A critical event is defined as "...any situation faced by emergency service provider that causes them to experience unusually strong emotional reactions, which have the potential to interfere with their ability to function either at the scene or later" (Mitchell, 1983,p. 36). These situations include exposure to incidents involving: injury or death of a victim, injury or death of a fellow emergency responder, a threat to an emergency responder's safety or life, a failed rescue (i.e. subsequent death of a victim), or an unusual and problematic emergency operation (Mitchell, 1983).

The Critical Incident Inventory questionnaire was developed specifically to assess firefighters' exposure to critical events (Monnier et al., 2002). This questionnaire strives to quantify firefighters' firefighters' exposure to critical events that could be experienced through the performance of their daily job responsibilities (Monnier et al., 2002). A critical gap in research focused on mental health among first responders including firefighting, is understanding the total burden of psychological factors associated with critical incident exposure and the link to post-traumatic stress disorders. Understanding the impact of these psychological factors may help mitigate the high post-traumatic stress injury burden prevalent among firefighters (Guidotti, 1992; Hytten & Hasle, 1989; Mitchell & Dyregrov, 1993; Ward, Lombard, & Gwebushe, 2006).

1.6 Firefighting as a Context for Identifying Musculoskeletal Injury Risk Factors

The high physical and psychological demands associated with firefighting provides a unique occupational context for understanding mechanisms of MSK injury risk. Firefighters experience higher incidence of MSK injuries than workers in other occupations (Walton et al., 2003; Workplace Safety and Insurance Board, 2015). This high rate of injuries is a result of the high physical and psychological demands of their job (Walton et al., 2003). Physical demands of an occupation or job refer to biomechanical (i.e., postures and heavy load) and physiological stressors (i.e., cardiorespiratory loads) associated with the nature of a job (i.e., awkward postures, heavy lifting, fast pace). Psychological demands associated with a job are in reference to the psychological stressors such as job satisfaction, psychosocial factors, and more commonly in firefighting, exposure to critical events (witnessing traumatic events such as death) (Conrad, Balch, Reichelt, Muran, & Oh, 1994). While many of the physical and psychological demands associated with firefighting have been identified in literature, the effect of cumulative exposure to these demands has not been widely researched (Conrad et al., 1994; Manning & Griggs, 1983; Monnier et al., 2002). Various theories suggest that repeated exposure to physical and psychological loads contribute to an increased risk of MSK injuries however, this has not yet been explored in a firefighting context (Kumar, 2001; Zhang & Yu, 2010). The high occupational demands and rates of injury among the firefighting population indicates a strong need for assessment of injury risk factors in a firefighting context. Examining exposure to both physical and psychological risk factors, over time, and their association with MSK injury risk, provides novel information about an at-risk population that may further the development of a comprehensive injury prevention strategy. The overarching goal of this thesis was to use the findings of this research to inform the development of effective injury prevention strategy for firefighters.

1.6.1 Injury Burden in Firefighters

Structural firefighting is considered to be a high-risk occupation resulting in high incidences of occupational injuries, diseases, and disorders (Walton et al., 2003). Firefighters experience higher rates of MSK injuries, burn and inhalation injuries, as well as higher rates of occupational diseases such as cancers, respiratory diseases, and post-traumatic stress disorder than any other occupations (Reichard & Jackson, 2010). Firefighting tasks are physically demanding, often requiring high physical exertions during fire suppression and training activities (Guidotti, 1992). These tasks often result in overexertion, a known risk factor for MSK injury and is identified as the leading cause of MSK injury among firefighters (Karter and Badger, 2001). Previous studies found that overexertion was the cause of 31.4% of all firefighter injuries (Walton et al., 2003). Strains and sprains accounted for 72.7% of all lost-time and worker compensation injuries (Walton et al., 2003). Furthermore, overexertion related injuries were associated with higher workers' compensation costs (Walton et al., 2003). These costs were approximately $1500 more than the per claim average for injuries overall. In addition, injuries resulting in sprains and strains were 80% more costly than that of other injury types (Walton et al., 2003). This indicates a strong need for the development and implementation of injury prevention strategies to mitigate impacts of firefighting occupational risks.

1.6.2 Risk Factors

The functional demands associated with firefighting and the environment within which firefighting tasks are performed provide a unique context to study the mechanisms precipitating MSK. In particular, firefighting is non-cyclical work in which physically demanding tasks occur intermittently (Michaelides, Parpa, Henry, Thompson, & Brown, 2011). Furthermore, firefighters are exposed to many psychological stresses that impact their mental health (Guidotti, 1992). The interaction between physical and psychological demands in firefighting and corresponding impact on MSK injury risk is less clearly understood. Further understanding of the relationship between physical and psychological demands will improve targeted development of injury prevention strategies.

1.6.2.1 Physical Demands and Musculoskeletal Injury Risk Factors in Firefighting

The physical demands and MSK injury risk factors in firefighting include biomechanical and physiological strain/load resulting from firefighting tasks, personal protective equipment (PPE) worn, as well as environmental factors (Guidotti, 1992). Firefighters are required to perform work tasks under extreme conditions (i.e. fire) that are often physiologically taxing and require performance of strenuous tasks in challenging work environments (Michaelides et al., 2011). The nature of firefighting tasks often involves heavy lifting, unsafe and awkward work postures, and high physiological demands, placing firefighters at high risk of injury (Takala et al., 2010). Examples of the most strenuous firefighting tasks include an aerial ladder climb, rescue of a victim, hose drag, and ladder raise as determined both subjectively by firefighters as well as objectively through energy cost analysis (VO2 analysis) (Lemon & Hermiston, 1977; Taylor, Lewis, Notley, & Peoples, 2012). For the purpose of this study, a greater focus will be placed on the demands associated with the hose drag and an adapted victim rescue tasks (patient transfer into stair chair). These tasks often require heavy lifting while firefighters are in awkward postures, navigating challenging environments such as extreme temperatures, fallen obstacles, and limited visibility due to smoke (Windisch, Seiberl, Hahn, & Schwirtz, 2017). This places high loads and forces on joints and tissues (Gentzler & Stader, 2010). In addition, firefighters have to perform these tasks quickly under pressure, increasing the physiological demands associated with the performance of these tasks (Windisch et al., 2017). These aspects of the tasks place firefighters at high risk of injury during their performance.

In addition to the physical demands associated with firefighting tasks, firefighters are required to wear personal protective equipment (PPE) during all firefighting tasks adding to the physical demands experienced during task performance. Personal protective equipment worn by firefighters includes turnout gear, boots, and a self-contained breathing apparatus (SCBA) and is essential in preventing burns, smoke inhalation and cardiovascular injury (Guidotti, 1992). It is important to note that not all equipment is worn for the performance of all tasks. Firefighters may remove some articles of PPE during the performance of certain tasks, as required. For example, during the performance of a patient transfer task, the SCBA is removed. Regardless, PPE has been shown to increase physical burden on firefighters during various task performance (Bruce-Low, Cotterrell, & Jones, 2007; Lee, Bakri, Kim, Son, & Tochihara, 2013; Park, Hur, Rosengren, Horn, & Hsiao-Wecksler, 2010; Taylor, Lewis, Notley, & Peoples, 2012). For example, a decrease in exercise tolerance of 56% and a 35% elevation in physiological strain was observed among firefighters when performing a treadmill walking task where boots and turnout gear had the most significant impact on physiological status (Taylor et al., 2012). Personal protective equipment has also been shown to impact task performance and is closely linked with the incidence of MSK injuries such as sprains and strains (Park et al., 2010). This is due to the added weight and bulk of this equipment increasing the kinematic burden of task performance by obstructing firefighters' mobility during movement (Adams & Keyserling, 1995; Huck, Maganga, & Kim, 1997). Furthermore, turnout gear worn alone (without boots and SCBA) has been shown to significantly decrease ROM of hip and knee in the sagittal and transverse planes which may increase the amount of exertion applied during movement, increasing physical effort and therefore physiological demand (through energy expenditure) as well as increased physical strain (through compensatory movement) leading to MSK injury (Park et al., 2015).

The protective boots worn by firefighters weighing up to 4.4 kg, add to the incumbent weight of the overall firefighter PPE and impact task performance. (Chiou, Turner, Zwiener, Weaver, & Haskell, 2012). Therefore, like the turnout gear, these boots impose a physical burden, through an increase in physiological demands as well as a decrease in mobility of the feet and ankles (Park et al., 2015; Taylor et al., 2012). These factors impact how firefighters perform their work tasks, resulting in a higher risk of injury.

The combination of high demand tasks, extensive PPE, and potential psychological factors imposes a rapid and extreme increase in heart rate in response to the demands; for example, firefighters reach a heart rate of 70%-80% of their maximum within the first minute of firefighting after which they maintain a heart rate of 85%-100% of maximum throughout (Guidotti, 1992; Manning & Griggs, 1983). These demands, paired with environmental hazards, in which they must be performed, increase personal fluid loss and the risk of a heat stress event, further enhancing the overall risk of injury and death (Stevenson, 1985). Note that a primary limitation of these studies is that firefighting tasks were simulations in a controlled laboratory setting and were assessed as one point in time; impacts and potential adaptations associated with cumulative exposures were not identified.

1.6.2.2 Psychological Demands and Risk Factors in Firefighting

In addition to the typical psychological stresses associated with that of any occupation (job satisfaction, autonomy, supervisor and peer group support, career advancement, etc.) firefighters are faced with many other job-specific psychological stresses (Guidotti, 1992;

Treaster & Burr, 2004). Fire-specific sources of job-related stress include: anxiety induced by alarms, personal safety, the safety of others, and social expectations (Guidotti, 1992). The call to perform strenuous tasks in stressful situations begins with the sound of an alarm, an immediate source of anxiety for firefighters (Takeyama et al., 2005). This suggests that firefighters enter these emergency response situations with an elevated level of stress and sympathetic response. Once at the scene of an emergency situation, firefighters incur a high degree of personal risk through their occupational tasks, often running into a situation that causes others to flee instinctively, due to the level of associated danger. These emergency response situations are often unpredictable (Guidotti, 1992). In addition to their personal safety, firefighters are responsible for protecting the safety of others through victim rescues. Often through victim rescues, firefighters are subjected to what is anecdotally deemed one of the most stressful experiences: a failed rescue, especially that of a child (Guidotti, 1992). Through victim rescues, firefighters witness critical incidents such as gruesome injuries, pain, and strong emotion, ensuing a great deal of stress for firefighters.

The burden associated with critical event exposures and the corresponding impact on firefighters' psychological health has been previously explored (Mitchell & Dyregrov, 1993; Weiss, Marmar, Metzler, & Ronfeldt, 1995). Findings of these studies indicated a need for the development of a tool to assess the relationship between exposure to these critical events and psychological functioning (Monnier et al., 2002). Monnier, Cameron, Hobfoll, and Gribble developed the Critical Incident Inventory to address this gap and assess the impact of critical incident exposure on psychological functioning (2002). The primary purpose of the tool is to quantify critical incident exposure. The CII is a 24-item questionnaire with six subscales inclusive of traumatic events that's firefighters a likely to experience in their line of work.

1.7 Research Problem

Although biomechanical, physiological, and psychological factors have been established as contributors to MSK injury risk, obtaining these measures in a firefighting context, particularly over multiple timepoints, has not been previously explored. Measuring these factors over time allows for the understanding of cumulative effects of physical and psychological load and their impacts on MSK injury and adaptation to stressors. Furthermore, research considering impacts of psychological factors on work health in a firefighting context is limited. Measuring physiological and psychological load throughout task performance and over various time points provides insight on the cumulative effects of stressors and their impact on firefighters' health. However, previous studies assessing these demands have been cross-sectional, measuring physical and psychological demands at one point in time (Basinska & Wiciak, 2012; Chiou et al., 2012; Dutton, Smolensky, Leach, Lorimor, & Hsi, 1978; Haugen, Evces, & Weiss, 2012; Huang, Acevedo, Garten, Wade, & Webb, 2009; Hytten & Hasle, 1989; Kaikkonen et al., 2017; J. Y. Lee et al., 2013; H. Park et al., 2015; Taylor et al., 2012). While this work has been foundational in improving the understanding of the burden of injuries in firefighters, it poses limitations for understanding the cumulative effects of these demands.

The results of the studies contained within this thesis can help emergency responders, researchers, clinicians, and policymakers understand the effects of exposure to various MSK injury risk factors and how exposures vary over time. This information in turn will allow them to tailor context specific MSK injury prevention initiatives to address the multifactorial causation of MSK injury.

1.8 Purpose

The purpose of this research is to improve understanding of Thunder Bay Fire Rescue (TBFR) firefighters' physical and psychological risk factors over time. This study aims to quantify: i) MSK injury risk, ii) physiological load, and iii) critical incident exposure; as well as assess changes in these variables over a 1-year period.

To determine the aforementioned, the following research questions and associated hypotheses were developed and answered in the following papers:

Paper 1 (Chapter 2): *Career firefighters' physiological load and musculoskeletal injury risk during firefighting task performance*

1) What is the MSK injury risk and physiological load associated with firefighting tasks among TBFR firefighters?
2) What is the variability in firefighters' MSK injury risk and physiological response to simulated fire response activities over one year?

As per Folkard and Åkerstedt (2004) it is anticipated that firefighters' measures of HRV will decrease over 1-year. Based on the Cumulative Load Theory proposed by Kumar (2001) it is anticipated that firefighters' MSK injury risk will increase over one year.

Paper 2 (Chapter 3): *Identifying critical incident exposure among Thunder Bay Fire Rescue firefighters*

3) What is firefighters' exposure to critical events at three timepoints over one year?
4) What is the variability in firefighters' exposure to critical events over one year?

Anecdotal evidence related to critical incident exposure and call volume provided by firefighters suggests no significant variability in firefighters' exposure to critical events over 1-year was anticipated.

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Chapter 2: FIREFIGHTERS' PHYSIOLOGICAL LOAD AND MUSCULOSKELETAL INJURY RISK DURING SIMULATION OF TWO FIREFIGHTING TASKS

2.1 Abstract

Background: Firefighting is a physically demanding job that requires firefighters to perform strenuous work tasks under extreme conditions. The combination of strenuous work tasks performed in challenging work environments often results in higher rates of injury and illness among firefighters (Michaelides et al., 2011; Reichard, 2010). The objectives of this study were to: 1) quantify physiological response to simulated firefighting tasks; 2) assess the variability in physiological response to those tasks over one year; 3) quantify musculoskeletal (MSK) injury risk associated with performance of those tasks; 4) assess variability in MSK injury risk associated with task performance among Thunder Bay Fire Rescue (TBFR) firefighters.

Methods: Physiological load and MSK injury risk were collected from a sample of 39 TBFR firefighters at 3 timepoints: baseline (November 2017), six-months (May 2018), and one-year (November 2018). Firefighters performed two firefighting tasks; a hose drag task and a patient transfer task. Physiological load was measured using heart rate and heart rate variability, collected using a Zephyr BioHarness worn during the performance of two firefighting tasks. Heart rate data was normalized as a percentage of participants' age-predicted maximum HR. The Ovako Working Posture Analysis System was used to determine MSK risk from video data of firefighters performing a hose drag and patient transfer task. Descriptive statistics (mean, standard deviation, minimum, and maximum) for heart rate (HR), HR as a % of maximum, heart rate variability (HRV), and MSK injury risk (median and range) were produced for each task at each time point. Additionally, a series of repeated measures one-way analyses of variance (ANOVA) were conducted to assess variability in HR, HR as a % of maximum, and HRV over

one year. The Friedman test was conducted to determine variability in MSK injury risk over one year.

Results: Findings indicated that physiological load during performance of a simulated hose drag and patient transfer task is moderate to high across timepoints as determined by HR as a percentage of age-predicted maximum HR. These intensities were determined as per the Health Canada and Canadian Society for Exercise Physiology physical intensity guidelines (1998). Additionally, HRV was low (<100 ms) across all time points and all tasks, although increased during the performance of the patient transfer task over a one-year period ($F(2, 26) = 5.2030$, $p < .05$, $\eta_{p2} = .287$). Musculoskeletal injury risk was moderate (*Mdn* = 2; hose drag – end) to high (*Mdn* = 4; hose drag start) and was consistent for each task across timepoints.

Discussion: These findings suggest TBFR firefighters' exposures to physiological demands and MSK injury are high during performance of simulated firefighting tasks with no variability in MSK injury risk over one year. Findings may have implications for better understanding mechanisms of MSK injuries in firefighting. Comprehensive interventions considering physiological and biomechanical factors are required to mitigate impacts associated with firefighting task demands.

2.2 Introduction

Firefighters contribute to the health and safety of the communities in which they serve. Through their occupational tasks, firefighters are exposed to many injury risk factors. As a result, firefighters experience high rates of injury compared to other occupations, with the majority being musculoskeletal (MSK) injuries such as sprains and strains (Conrad et al., 1994; Guidotti, 1992; Reichard, 2010; Walton et al., 2003). Firefighting tasks are physically demanding, often requiring high physical exertions during fire suppression and training activities. Often, these tasks result in overexertion, which has been identified as the leading cause of injury among firefighters (Karter and Badger, 2001). Previous studies examining the cause and types of injuries in firefighters found that overexertion was the cause of 31.4% of all firefighter injuries (Walton et al., 2003). Overexertion is defined as “a physical activity in which the level of effort exceeds normal physiological and mechanical (physical) tolerance limits” (Kumar, 1994). When physical effort exceeds tolerance, injuries such as sprains and strains are likely to occur. Sprains and strains account for 72.7% of all lost-time and worker compensation injuries (Walton et al., 2003). A study conducted to determine the costs associated with injuries sustained by firefighters determined that injuries caused by overexertion were associated with higher workers’ compensation costs (Walton et al., 2003). These costs were approximately $1500 more than the per claim average for injuries overall. In addition, injuries resulting in sprains and strains were 80% more costly than that of other injury types (Walton et al., 2003). These occupational injuries and illnesses place physical, emotional, and financial burdens on the firefighters themselves, their families, and impact their communities on an organizational level. This indicates a strong need for the development and implementation of injury prevention strategies.

2.2.1 Occupational Demands in Firefighting

There are many recognized individual and work-related risk factors that contribute to MSK risk. Kumar (2001) describes MSK injury causation as multifactorial; the Multivariate Interaction Theory of Musculoskeletal Injury Precipitation describes how MSK injury causation is an interaction between various risk factors (Kumar, 2001). These factors act individually and in combination to impact the MSK system resulting in strain, structural changes, and biomechanical changes to anatomical structures, which further induce pain (Karsh, 2006). Biomechanical factors resulting in injury are a result of physical exertions involving a large number of muscles, bones, ligaments, tendons and joints. This research has been used to determine workplace hazards which include posture, range of motion, force, repetition, and duration (Westgaard & Winkel, 1997). Knowledge of these risk factors has been used to develop injury prevention strategies including tool kits that can be implemented in various occupational contexts (OHSCO, 2008). Despite the existence of these tools and knowledge of MSK injury risk factors, injury rates amongst firefighters remains high (Negm et al., 2017; Reichard, 2010). A greater understanding of the occupational demands and specific risk factors associated with firefighting contexts will enable development of comprehensive context specific injury mitigation strategies that may be effective at reducing this high injury burden.

In addition to the biomechanical MSK injury risk factors firefighters are exposed to, there a number of physiological factors that may influence firefighter injury risk. Firefighters are required to perform work tasks under extreme conditions that are often physiologically demanding and require performance of strenuous tasks in challenging work environments (Michaelides et al., 2011). The nature of firefighting tasks often involves heavy lifting, unsafe and awkward work postures, and high physiological demands, placing firefighters at high risk of injury (Takala et al., 2010). Examples of the most strenuous firefighting tasks include an aerial ladder climb, rescue of a victim, hose drag, and ladder raise as determined both subjectively by firefighters as well as objectively through energy cost analysis (VO2max testing; Lemon & Hermiston, 1977). For the purpose of this study, a greater focus was placed on the demands associated with the hose drag and an adapted victim rescue tasks (i.e., patient transfer into stair chair). These tasks often require heavy lifting while firefighters are in awkward postures, navigating challenging environments such as extreme temperatures, fallen obstacles, and limited visibility due to smoke (Windisch et al., 2017). This places high loads and forces on joints and tissues (Gentzler & Stader, 2010). In addition, firefighters are required to perform these tasks quickly under pressure, increasing the physiological demands associated with the performance of these tasks (Windisch et al., 2017). These biomechanical and physiological aspects of the tasks place firefighters at high risk of injury during their performance.

2.2.2 Measures of Biomechanical and Physiological Factors of Musculoskeletal Injury

The interaction between biomechanical and physiological factors play a role in MSK injury causation. This highlights the importance of measuring and understanding the impacts of these factors during the performance of work tasks in order to develop effective injury mitigation strategies.

2.2.2.1 Measures of Physical Load

Understanding the physical demands of a job requires measurement and observation of job tasks. Kinematic and kinetic analysis of job tasks allows practitioners to assess the postures required and forces generated by a worker during the performance of their job tasks. Another frequently used method to understand physical risk factors in an applied work setting is the use of observational risk assessment tools. These tools are designed for use in various work settings to evaluate physical workload and identify hazards in the workplace (Takala et al., 2010).

A frequently used observational risk assessment tool for describing workloads is the Ovako Working Posture Analysis System (OWAS). This tool considers aspects such as postures and weight of the loads handled to describe MSK injury risk associated with the task and the need for ergonomic intervention to mitigate injury risk. Factors such as posture and load are directly linked to MSK injury causation and are important considerations for understanding MSK injury risk in the workplace. As previously mentioned, firefighters are exposed to these risk factors through task performance. Therefore, understanding these demands associated with a task will allow for the development of informed injury prevention strategies.

2.2.2.2 Measures of Physiological Load

In addition to quantifying biomechanical injury risk exposures, physiological measures also provide insights on the physical demands of a job. While many studies have considered the importance of understanding physiological factors for MSK injury risk, research quantifying physiological demands is limited (Gentzler & Stader, 2010; Westgaard & Winkel, 1997). Although research on the impacts of physiological load on MSK health is limited, there is evidence to suggest that physiological factors play a role in MSK causation (Westgaard & Winkel, 1997). Strenuous job tasks result in acute physiological response that can result in the experience of fatigue, discomfort, pain, and reduced productivity (Kumar, 1994; Shen et al., 2006; Westgaard & Winkel, 1997). Firefighting is a physically demanding occupation with high physiological loads experienced during the performance of firefighting tasks (Romet & Frim, 1987). Heart rate is commonly used as measure of physiological load where higher HRs are often observed during the performance of more strenuous tasks. High HRs and working intensities, as determined by HR as a percentage of APMHR, have been measured during the performance of firefighting tasks, indicating the firefighters are exposed to high physiological loads (Lindberg, Oksa, Gavhed, & Malm, 2013; Romet & Frim, 1987). One limitation of using HR as a raw measure of physiological load is that it has not been normalized to enable cross-individual comparisons. Heart Rate as a percentage of age predicted maximum facilitates this comparison and improves within group comparisons.

Another physiological measure that can provide insights on physiological strain and tolerance to physiological strain is HRV. Heart rate variability is the change in time intervals between successive heartbeats (Shaffer et al., 2014). Heart rate variability provides information on the various interacting physiological and neural systems that operate to adapt to various challenges and stressors (Shaffer et al., 2014). A decreased HRV is linked to an increase in sympathetic activity of the autonomic nervous system and is often observed with an increase in HR (Shaffer et al., 2014). This is usually a strong indicator of physiological load or psychological stress. Cumulative exposure to these stressors can result in the experience of fatigue (Westgaard & Winkel, 1997). Furthermore, there is evidence in the literature that suggests that fatigue plays a role in MSK injury causation (Conrad et al., 1994).

The high physiological loads associated with firefighting tasks exposes firefighters to physiological strain. Evidence in the literature indicate that physical and physiological factors play a role in MSK injury, however these factors are often measured independently of each other. There is a need for a better understanding of physiological load and their impacts on MSK health. Furthermore, there is a need to better understand the impacts of these factors in a firefighting context.

2.2.3 Research Objective

The purpose of this study was to quantify physiological loads and MSK injury risk associated with two frequently performed strenuous firefighting tasks and their cumulative impacts over time among Thunder Bay Fire Rescue (TBFR) firefighters. As such, HR, HR expressed as a percentage of age-predicted maximum, HRV, and OWAS score were determined for each task at each timepoint. An additional objective of this research was to determine whether physiological tolerance to task demands and MSK injury risk changed over a one-year period.

2.3 Method

2.3.1 Study Design

The purpose of this study was to quantify physiological loads and MSK injury risk associated with two frequently performed strenuous firefighting tasks and their cumulative impacts over time among Thunder Bay Fire Rescue (TBFR) firefighters. As such, HR, HR expressed as a percentage of age-predicted maximum, HRV, and OWAS score were determined for each task at each timepoint. An additional objective of this research was to determine whether physiological tolerance to task demands and MSK injury risk changed over a one-year period.

2.3.2 Context

In order to simulate the demands associated with firefighting tasks, all study components were performed at the TBFR training facility; this allowed access to all firefighting equipment. Two frequently performed, physically demanding firefighting tasks were included, as identified by firefighters and further supported in the literature. Task performance was videotaped for further analysis of work postures for determination of injury risk. Additionally, a Zephyr BioHarness was used to enable continuous monitoring of physiological load during task performance.

2.3.3 Participants

A sample of 40 participants was recruited from the Thunder Bay Fire Rescue (TBFR) at the baseline timepoint, inclusive of active-duty (*n* = 32) and recruit *(n* = 8) firefighters between the ages of 23 and 58 years old (*SD* = 8.7). Participants included male (*n* = 39) and female (*n* = 1) firefighters. Exclusion criteria included injuries that rendered participants incapable of performing firefighting tasks or were performing work tasks with modifications.

2.3.4 Data Collection

A demographic questionnaire was developed and administered to collect data on firefighters' age, sex, height, weight, number of years served as a firefighter, and job title/rank (Appendix A). After participants were informed of the experimental procedure, they provided written consent and completed the questionnaires. Participants were fitted with the Zephyr BioHarness (BioHarness 3.0; Zephyr Technology Corp., Annapolis, Maryland, USA) as per the manufacturer's guidelines and donned all turnout gear including the self-contained breathing apparatus (SCBA) before task performance. Participants were asked to execute two, frequently performed tasks, which were subjectively deemed by the participants to be the most physically demanding. The two tasks were: a hose-drag task, and a patient transfer. During task performance, video data was collected in the sagittal plane of movement for further analysis of MSK injury risk.

2.3.4.1 Hose Drag Task

The hose drag task was performed using a 150 ft, charged length of hose (1000 kpa). The task began with participants in a standing position with the nozzle of the hose positioned on the floor beside their feet. When instructed, they retrieved the nozzle of the fire hose from the ground and dragged the hose a distance of 100 ft. Participants were not given details on how to perform the task but were instructed to perform the task as they would in a fire setting. Firefighters were told to approach the task as though they were approaching a garage fire with no life in danger. This description set the context for the simulated hose drag task. The nozzle was then discharged using a "straight stream" setting for five seconds. After completion of the hose drag task participants performed the patient transfer task (**Error! Reference source not found.**).

2.3.4.2 Patient Transfer Task

The patient transfer task was performed as a two-person lift requiring participants to lift a 68 kg manikin from the floor into a stair chair (**Error! Reference source not found.**). The manikin used for the performance of this task is also used by firefighters for training purposes and is weighted to simulate human anthropometry where the torso is weighed more heavily than the lower limbs. Participants remained in their turnout gear for this task with the exclusion of the SCBA and helmet as they typically would not be wearing these items during performance of this task. Additionally, they wore sterile nitrile gloves as they would in the field setting. The lift was performed twice; once lifting at the head of the manikin (heavy end) and once lifting at the feet of the manikin (light end).

Figure 2.1. Patient transfer into stair chair task performance.

2.3.5 Measures

Demographic information was collected prior to task performance. Physiological, and kinematic measures were collected throughout task performance.

2.3.5.1 Demographic Questionnaire

Demographic information was collected using a demographic questionnaire developed by the research team including input from the firefighter research partners (Appendix A). Information collected included age, sex, height, weight, number of years served as a firefighter, and job title/rank. This data was used during statistical analysis to describe the sample.

2.3.5.2 Physiological Response

Firefighters' heart rate and heart rate variability during task performance was measured continuously using a Zephyr BioHarness device (See Figure 4). This device is a wearable physiological status monitor with the capacity to collect, store and transmit measures on a number of variables with a high degree of validity and reliability in both lab and field-based studies (Johnstone, Ford, Hughes, Watson, Mitchell, et al., 2012; Johnstone, Ford, Hughes, Watson, & Garrett, 2012a, 2012b). This data was expressed as a percentage of age-predicted maximum. Each participant wore the BioHarness directly against the skin around the chest via the provided chest strap (**Error! Reference source not found.**). The BioModule, which is the monitoring device, was attached to the strap underneath the left armpit as per the manufacturer's guidelines. Heart rate variability data is captured through a single ECG lead embedded within the chest strap. The ECG channel samples R waveforms at a frequency of 250 Hz that was further processed to determine HRV.

Figure 2.2. Zephyr BioModule, BioHarness, and appropriate placement of chest strap.

2.3.5.3 Musculoskeletal Injury Risk

Musculoskeletal injury risk was estimated using an observational risk assessment tool. The OWAS uses observation of posture and load handled to determine MSK injury risk and need for ergonomic injury prevention intervention. There is evidence of moderate validity and good intra- and inter- rater reliability of the OWAS to quantify MSK injury risk (Takala et al., 2010). Posture of the back (three postures), arms (three postures), lower extremities (seven postures), and load handled (three categories) were assessed. Depending on the combination of each of the postures in combination with the load, one of four categories was determined, describing MSK injury risk and need for intervention.

Video data was collected through the use of two digital video recorders (Panasonic HC-V550; Panasonic Corporation, Kadoma, Osaka, Japan) positioned to capture movement in the sagittal plane. During performance of the hose drag task, one camera was placed at the starting point and another placed at the end of the 100ft distance to capture posture at the end phase of the hose drag task; both cameras were placed on the right side of the participant. During performance of the patient transfer task, one camera was placed on the right and another on the left side of the participants. Video data (AVI files) was exported from the cameras and imported into Dartfish movement analysis software (Version 9.0 ProSuite, Dartfish, Fribourg, Switzerland) where researcher observation of upper limb, lower limb, and trunk was noted for input into the OWAS ergonomic risk assessment tool. The use of Dartfish was used solely to facilitate clear observation of the tasks for application of the OWAS tool to stratify injury risk. The score associated with each posture was determined using OWAS, accessed through ErgoFellow software (Version 3.0; FBF Sistemas Ltda., Belo Horizonte, MA, Brazil) for determination of MSK injury risk during task performance (Takala et al., 2010).

2.3.6 Statistical Analysis

All data analyses were conducted through version 25 of the Statistical Package for the Social Sciences© (SPSS). Descriptive statistics (mean, standard deviation, minimum, and maximum values) were produced for age, height, weight, years of service, HR, HR as a percentage of maximum, HRV, and MSK injury risk (median).

A series of one-way repeated measures Analysis of Variances (ANOVAs) were conducted to determine whether firefighters' physiological response to firefighting tasks changed over one year. A preliminary evaluation of outliers, normality, and sphericity was conducted before conducting these analyses. Separate ANOVAs were conducted for each dependent variable, for each task. In each ANOVA, HR and HRV score were entered as the dependent variable and time was entered as the independent variable (baseline, 6-months, 1-year). A Bonferroni post-hoc analysis was performed to better understand the specific time points at which HR and HRV differed.

The Friedman test was conducted to determine variability in firefighters' MSK injury risk across time. The Friedman test, known as the non-parametric alternative to the one-way repeated measures ANOVA test, was used to determine whether the ordinal variable of MSK injury risk changes across the three levels of the independent variable of time (baseline, 6-months, 1-year). Post-hoc pairwise comparisons were performed with a Bonferroni correction for multiple comparisons to determine the specific time points at which MSK injury risk differs.

2.4 Results

2.4.1 Demographics

The participant sample recruited for this study consisted of male (n = 39) and female (n = 1) new recruit and active-duty firefighters. Participation varied over the one-year period with an 8% attrition rate at the six-month time point (n = 36) and a 10.9% attrition rate by the one-year time point (n = 35). Participants were an average age of 37 (+/- 8.7) years old at recruitment and had been firefighting for a mean of 9.2 (+/- 8.0) years. On average, participants were 183.82 (+/- 7.37) inches tall and weighed 90.75 (+/- 10.16) pounds (lbs). There was no significant change in participant weight over the one-year period, $F(2, 66) = .570$, $p = .568$. A full summary of participant demographics over each time point can be found in **Error! Reference source not found.**.

Table 2.1

Descriptive statistics for demographic data from participating firefighters

	Mean	Standard Deviation	Minimum	Maximum
Baseline				
Age	37.0	8.7	23	58
Height	183.82	7.37	167.64	198.12
Weight	90.75	10.16	75.74	113.38
Yrs. Of Service	9.2	8.2	.42	29
Six-months				
Age	37.4	9.0	24	58
Height	183.90	7.24	167.64	198.12
Weight	90.34	11.70	61.22	113.39
Yrs. Of Service	9.5	8.3	.5	30
One-year				
Age	38.7	8.9	24	59
Height	183.74	6.91	167.64	198.12
Weight	90.93	11.70	73.92	115.65
Yrs. Of Service	10.6	8.3	1	30

2.4.2 Descriptive Statistics

Descriptive statistics were produced for all dependent variables to quantify HR, HRV, and MSK injury risk during task performance at each of the three timepoints (baseline, six-months, one-year).

2.4.2.1 Heart Rate

Descriptive statistics for HR data are presented in **Error! Reference source not found.** for each task at each timepoint. Raw HR data was normalized as a percentage of participants' age-predicted maximum HR (APMHR).

2.4.2.1.1 Hose Drag Task

Participants average HR was 119 (+/- 19.5) beats per minute (bpm) during performance of the hose drag task at baseline. Participants were working at an average of 64.7% of their APMHR suggesting a moderate-high physiological load associated with the task (Tremblay et al., 2007). Physiological load as determined by %AMPHR remained the same at the six-month timepoint with participants working at an average of 120 (+/- 16) bpm during task performance. Physiological tolerance to the task decreased at the one-year timepoint where firefighters worked at an average of 129 (+/-17) bpm and 69.6% of their APMHR.

2.4.2.1.2 Patient Transfer Task

The patient transfer task was completed twice, with each participant lifting once at the head of the weighted manikin (heavy) and once at the feet (light).

Patient transfer - head. On average, participants had an HR of 108 (+/- 16) bpm during performance of the patient transfer task while lifting at the head of the manikin at baseline. Participants worked at an average of 58.7% of their APMHR. This suggests that the task is moderately strenuous (Tremblay et al., 2007). Physiological load experienced by participants decreased at 6 months with participants working at an average HR of 106 (+/- 17) bpm and 57.2% of their APMHR. At the one-year timepoint, average task performance HR increased from the HR observed at the six-month timepoint to 108 (+/- 15) bpm and 58.3% of APMHR.

Patient transfer - feet. Participants average HR was 107 (+/- 16) bpm during performance of the patient transfer task while lifting at the feet of the manikin at baseline. Participants were working at an average of 58.2% of their APMHR. This suggests that the task was moderately strenuous (Tremblay et al., 2007). Physiological load experienced by participants decreased with participants working at an average HR of 106 (+/- 19) bpm and 57.2% of their APMHR. At the one-year timepoint, average task performance HR was lowest of all timepoints with participants working at an average HR of 103 (+/- 14) bpm and 55.6% of APMHR.

Table 2.2

Descriptive Statistics for Heart Rate Throughout Task Performance

	Mean	Standard Deviation	Minimum	Maximum	% of Age-predicted Maximum[a]
Baseline					
Hose Drag	119	19.5	75	155	64.7%
Patient Transfer					
Head (Heavy)	108	16.1	77	153	58.7%
Legs (Light)	107	16.4	74	143	58.2%
Six-months					
Hose Drag	120	16.1	83	162	64.7%
Patient Transfer					
Head (Heavy)	106	17.0	65	133	57.2%
Legs (Light)	106	19.1	70	140	57.2%
One-year					
Hose Drag	129	17.0	96	164	69.6%
Patient Transfer					
Head (Heavy)	108	14.7	90	142	58.3%
Legs (Light)	103	14.2	68	132	55.6%

Note. Heart rate reported in beats per min (bpm).
[a]Represents mean task performance heart rate as a percentage age-predicted maximum calculated using mean age of sample at each time point.

2.4.2.2 Heart Rate Variability

A summary of descriptive statistics for HRV data can be found in **Error! Reference source not found.**. Heart rate variability data is expressed in milliseconds as the standard deviation of normal to normal beats.

2.4.2.2.1 Hose Drag Task

On average, participants had an HRV of 73.3 (+/-32.82) ms during performance of the hose drag task at baseline. Physiological tolerance to the demands of the hose drag task decreased at the six-month timepoint as observed through a mean HRV of 63.9 (+/-33.34) ms during task performance. Average heart rate variability was highest during the performance of the hose drag task at the one-year timepoint at 75.8 (+/- 27.00) ms.

2.4.2.2.2 Patient Transfer Task

On average, a lower HRV was observed during the performance of the patient transfer task as compared to the hose drag task.

Patient transfer – head. Participants had a mean HRV of 51.65 (+/- 22.15) ms during performance of the patient transfer task at baseline while lifting at the head of the weighted manikin. Physiological tolerance of the task progressively increases at the six-month and one-year timepoints. The average HRV observed during task performance at six-months was 65.07 (+/-40.00) ms and 76.70 (+/- 25.00) at one-year.

Patient transfer – feet. Baseline measures of HRV indicated that average HRV during task performance was 55.20 (+/- 22.45) ms. Heart rate variability increased to 66.10 (+/- 43.15) ms at the six-month timepoint and further increased to 78.75 (+/- 33.68) ms at the one-year timepoint.

Table 2.3

Descriptive Statistics for Heart Rate Variability Throughout Task Performance at Each Timepoint

	Mean	Standard Deviation	Minimum	Maximum
Baseline				
Hose Drag	73.30	32.82	24.80	137.00
Patient Transfer				
Head (Heavy)	51.65	22.15	12.10	108.00
Legs (Light)	55.20	22.45	18.50	108.00
Six-months				
Hose Drag	63.88	33.34	16.00	158.30
Patient Transfer				
Head (Heavy)	65.07	40.00	16.90	158.00
Legs (Light)	66.10	43.15	18.80	158.40
One-year				
Hose Drag	75.77	27.00	21.31	147.86
Patient Transfer				
Head (Heavy)	76.60	25.00	24.67	123.33
Legs (Light)	78.75	33.68	24.88	153.60

Note. Heart rate variability reported as standard deviation of normal to normal intervals (SDNN) in milliseconds.

2.4.2.3 Musculoskeletal Injury Risk

Musculoskeletal injury risk descriptive statistics are presented in **Error! Reference source not found.**. Musculoskeletal injury risk was quantified using the OWAS posture analysis risk assessment tool. The OWAS ranks MSK injury risk and need for change to job tasks on a scale from zero to four, with action categories three and four requiring modification to the posture in the near and immediate future respectively. Musculoskeletal injury risk associated with task performance postures remains unchanged for each task across timepoints. The highest MSK injury risk is associated with the start phase of the hose drag task during which participants retrieve the nozzle of the hose from the ground to initiate the hose drag. The patient transfer task is associated with moderate risk, when participants lifted from both the light end and the heavy ends of the manikin. The end phase of the hose drag during which participants are in a stationary position, releasing the nozzle to discharge high pressure water, is associated with the lowest MSK injury risk.

Table 2.4

Descriptive Statistics for OWAS Injury Risk Assessment Categories During Task Performance

	Median	Interquartile Range
Baseline		
Hose Drag		
Start	4	1
End	2	0
Patient Transfer		
Head (Heavy)	3	1
Legs (Light)	3	0
Six-months		
Hose Drag		
Start	4	0
End	2	1
Patient Transfer		
Head (Heavy)	3	0
Legs (Light)	3	0
One-year		
Hose Drag		
Start	4	1

End	2	2
Patient Transfer		
Head (Heavy)	3	0
Legs (Light)	3	0

2.4.3 Inferential Statistics

A series of repeated measures one-way Analysis of Variance (ANOVA) tests were conducted to determine whether firefighters' physiological and physical response to firefighting tasks changed over a one-year period.

2.4.3.1 Heart Rate

This section provides results of the one-way repeated measures ANOVAs conducted to determine variability in participants' HR during the performance of the hose drag and patient transfer tasks over a one-year period.

2.4.3.1.1 Hose Drag Task

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in HR during the performance of the hose drag task over the course of a year. There were no outliers in the data as assessed by boxplot. Heart rate data at the baseline and one-year timepoints were normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$) while HR data at the six-month timepoint was not ($p = < .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi^2(2) = 1.428$, $p =.490$. Heart rate during hose drag task performance was significantly different across timepoints, $F(2, 48) = 4.685$, $p < .05$, $\eta_p^2 = 0.163$, with HR increasing from baseline ($M = 116.77$, $SD = 19.85$ bpm) to six-months ($M = 119.35$, $SD = 15.36$ bpm) to one-year ($M = 128.21$, $SD = 17.80$ bpm). Post hoc analysis with a Bonferroni adjustment revealed that HR was statistically significantly higher from baseline to one-year ($M = -11.44$ bpm, 95% CI [-22.60, -.28], $p < .05$), but not from baseline to six-months (M = -2.58 bpm, 95% CI [-11.60, 6.44], p = 1.00) or six-months to one-year (M = -8.86 bpm, 95% CI [-18.84, 1.12], p = .094).

2.4.3.1.2 Patient Transfer Task

The following section provides results of the repeated measures one-way ANOVAs conducted to determine variability in HR measures obtained during the performance of the patient transfer task over a one-year period.

Patient transfer – head. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in HR during the performance of the patient transfer task while lifting at the head of the weighted manikin over the course of a year. There were no outliers in the data as assessed by boxplot. Heart rate data at the baseline and six-month timepoints was normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$) while HR data at the one-year timepoint was not ($p = < .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi_2(2) = .893$, p =.640. There were no statistically significant differences in HR during task performance over time, $F(2, 42) = .054$, p = .948, $\eta_{p2} = .003$.

Patient transfer – feet. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in HR during the performance of the patient transfer task while lifting at the feet of the weighted manikin over the course of a year. There were a few outliers present in the data set at the baseline and one-year timepoints as assessed by boxplot. These outliers were considered to be true values and therefore were included in the analysis. Furthermore, the analysis was conducted with and without outlier data and produced similar results. Heart rate data was normally distributed at all timepoints, as assessed by the Shapiro-Wilk test ($p > .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi 2(2) = .430$, $p = .807$. There were no statistically significant differences in HR during task performance over time, $F(2, 44) = 1.018$, $p = .370$, $\eta_{p2} = .044$.

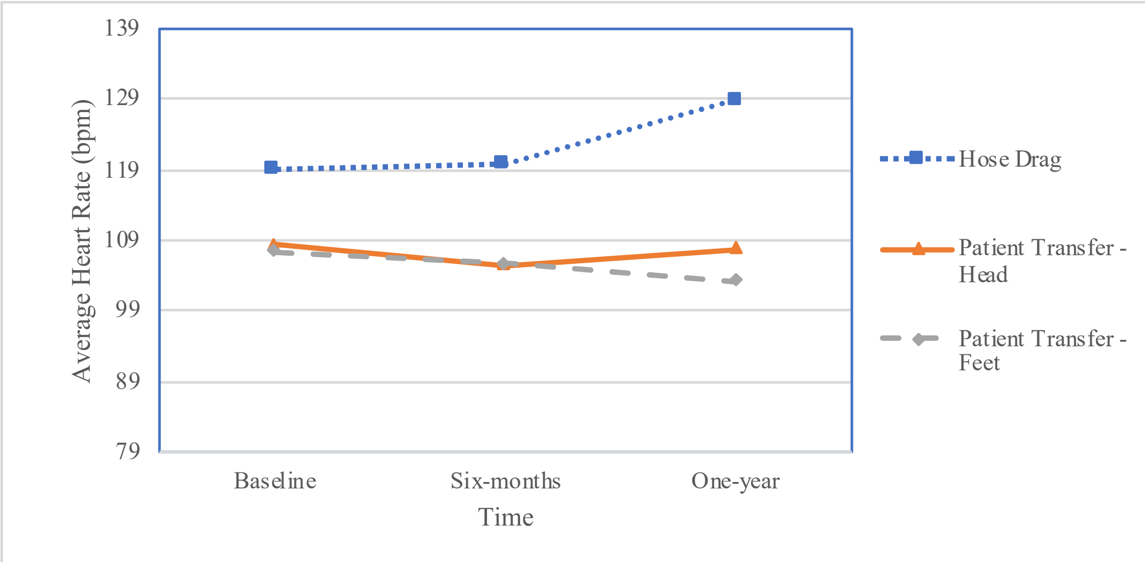

Figure 2.3. Average HR during task performance at each time point.

2.4.3.2 Working Intensity

This section provides results of the one-way repeated measures ANOVAs conducted to determine variability in participants' working intensity during the performance of the hose drag and patient transfer tasks over a one-year period.

2.4.3.2.1 Hose Drag

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in intensity during the performance of the hose drag task over the course of a year. There were no outliers in the data as assessed by boxplot. Intensity data was normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi 2(2) = .917$, $p = .368$. Intensity during hose drag task performance was significantly different across timepoints, $F(2, 48) = 5.598$, $p < .05$, $\eta_{p2} = 0.189$, with intensity increasing from baseline ($M = 64\%$, $SD = 11\%$ of maximum HR) to six-months ($M = 66\%$, $SD = 8\%$ of maximum HR) to one-year ($M =$

71%, *SD* = 11% of maximum HR). Post hoc analysis with a Bonferroni adjustment revealed that working intensity was statistically significantly higher from baseline to one-year (*M* = 7.4%, 95% CI [-.140, -.007], $p < .05$), but not from baseline to six-months (*M* = 2.1%, 95% CI [--.074, .033], $p = .978$) or six-months to one-year (*M* = 5.3%, 95% CI [-.108, .002], $p = .062$).

2.4.3.2.2 Patient Transfer Task

The following section provides results of the repeated measures one-way ANOVAs conducted to determine variability in intensity measures obtained during the performance of the patient transfer task over a one-year period.

Patient transfer – head. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in intensity during the performance of the patient transfer task while lifting at the head of the weighted manikin over the course of a year. There were outliers in the data as assessed by boxplot. These outliers were considered to be true values and therefore were included in the analysis. Furthermore, the analysis was conducted with and without outlier data and produced similar results. Intensity data at the baseline and six-month timepoints were normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$) while HR data at the one-year timepoint was not ($p = < .05$). The repeated measures one-way ANOVA was conducted despite this as the test is fairly robust to deviations from normality (Blanca, Alarcón, Bendayan, Arnau, & Bono, 2017). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi_2(2) = .941$, $p =.544$. There were no statistically significant differences in intensity during task performance over time, $F(2, 42) = .166$, $p = .848$, $\eta_{p2} = .008$.

Patient transfer – feet. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in intensity during the performance of the patient transfer task while lifting at the feet of the weighted manikin over the course of a year. There were a few outliers present in the data set at the baseline and one-year timepoints as assessed by boxplot. These outliers were considered to be true values and therefore were included in the analysis. Furthermore, the analysis was conducted with and without outlier data and produced similar results. Intensity data was normally distributed at all timepoints, as assessed by the Shapiro-Wilk test ($p > .05$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi_2(2) = .983$, $p = .833$. There were no statistically significant differences in intensity during task performance over time, $F(2, 44) = .539$, $p = .587$, $\eta_{p2} = .024$.

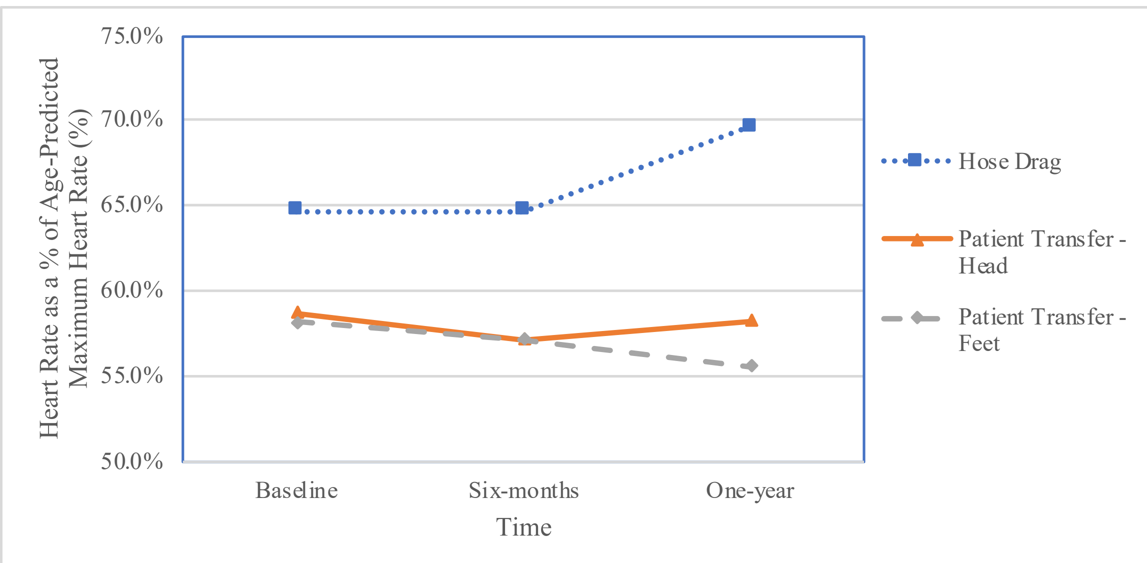

Figure 2.4. Average HR during task performance at each time point expressed as a percentage of age-predicted maximum.

2.4.3.3 Heart Rate Variability

This section provides results of the one-way repeated measures ANOVAs conducted to determine variability in participants' HRV during the performance of the hose drag and patient transfer tasks over a one-year period.

2.4.3.3.1 Hose Drag Task

A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in HRV during the performance of the hose drag task over the course of a year. There were a few outliers present in the data set at the six-month and one-year timepoints as assessed by boxplot. These outliers were considered to be true values and therefore were included in the analysis. Furthermore, the analysis was conducted with and without outlier data and produced similar results. Heart rate variability data was normally distributed at baseline as assessed by the Shapiro-Wilk test ($p > .05$) but not at the six-month ($p = .000$) and one-year ($p = .011$) timepoints. The repeated measures one-way ANOVA was conducted despite this as the test is fairly robust to deviations from normality (Blanca et al., 2017). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi_2(2) = .158$, $p = .942$. There were no statistically significant differences in HRV during task performance over time, $F(2, 28) = 1.455$, $p = .251$, $\eta_{p2} = .094$.

2.4.3.3.2 Patient Transfer Task

The following section provides results of the repeated measures one-way ANOVAs conducted to determine variability in HRV measures obtained during the performance of the patient transfer task over a one-year period.

Patient transfer – head. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in HRV during the performance of the patient transfer task while lifting at the head of the weighted manikin over the course of a year. There were no outliers in the data as assessed by boxplot. Heart rate variability data at the baseline and one-year timepoints were normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$) while HRV data at the six-month timepoint was not ($p = .008$). The repeated measures one-way ANOVA was conducted despite this as the test is fairly robust to deviations from normality (Blanca et al., 2017). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi^2(2) = 1.929$, $p = .381$. Heart rate variability during patient transfer task performance (lifting at the head) was significantly different across timepoints, $F(2, 26) = 5.2030$, $p < .05$, $\eta_p^2 = .287$, with HRV increasing from baseline ($M = 44.32$, $SD = 19.38$ ms) to six-months ($M = 57.01$, $SD = 37.13$ ms) to one-year ($M = 77.14$, $SD = 26.04$ ms). Post hoc analysis with a Bonferroni adjustment revealed that HRV was statistically significantly higher from baseline to one-year ($M = 32.89$ ms, 95% CI [10.604, 55.112], $p < .01$), but not from baseline to six-months ($M = 12.70$ ms, 95% CI [-18.962, 44.358], $p =.872$) or six-months to one-year ($M = 29.16$ ms, 95% CI [-9.462, 49.781], $p = .253$).

Patient transfer – feet. A one-way repeated measures ANOVA was conducted to determine whether there was a statistically significant difference in HRV during the performance of the patient transfer task while lifting at the feet of the weighted manikin over the course of a year. There were two outliers present in the data set at the six-month and one-year timepoints as assessed by boxplot. Heart rate variability data at the baseline and one-year timepoints were normally distributed, as assessed by the Shapiro-Wilk test ($p > .05$) while HRV data at the six-month timepoint was not ($p = .008$). The assumption of sphericity was met, as assessed by Mauchly's test of sphericity, $\chi^2(2) = 1.635$, $p = .442$. Heart rate variability during patient transfer task performance (lifting at the feet) was significantly different across timepoints, $F(2, 28) = 3.807$, $p < .05$, $\eta_p^2 = .214$, with HRV increasing from baseline ($M = 47.40$, $SD = 21.16$ ms) to six-months ($M = 60.31$, $SD = 42.55$ ms) to one-year ($M = 76.96$, $SD = 35.89$ ms). Post hoc analysis with a Bonferroni adjustment revealed that HRV was statistically significantly higher from baseline to one-year ($M = 29.56$ ms, 95% CI [2.044, 57.068], $p < .05$), but not from baseline to six-months (*M* = 12.912 ms, 95% CI [-20.841, 46.665], *p* =.948) or six-months to one-year (*M* = 16.644 ms, 95% CI [-9.036, 42.324], *p* = .300).

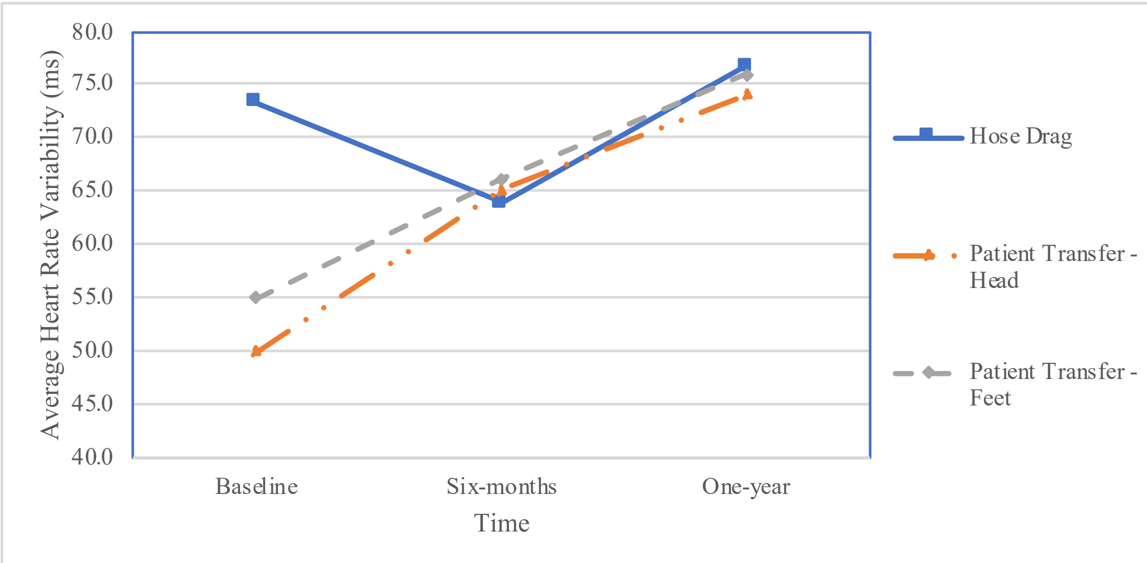

Figure 2.5. Average heart rate variability during task performance at each timepoint.

2.4.3.4 Musculoskeletal Injury Risk

This section provides results of the Friedman tests conducted to determine variability in firefighters' MSK injury risk during the performance of the hose drag and patient transfer tasks over a one-year period.

2.4.3.4.1 Hose Drag Task

This section provides results of the nonparametric Friedman test conducted to determine variability in firefighters' MSK injury risk during the performance of the hose drag task over a one-year period.

Hose drag start. A Friedman test was performed to determine if there were differences in MSK injury risk during the start phase of the hose drag task performance over a one-year period. Musculoskeletal injury risk remained the same from baseline (*Mdn* = 4), to six-months

(*Mdn* = 4), to one-year (*Mdn* = 4), as such there were no statistically significant differences, $\chi^2(2) = 4.308$, $p = .116$.

Hose drag end. A Friedman test was performed to determine if there were differences in MSK injury risk during the end phase of the hose drag task performance over a one-year period. Musculoskeletal injury risk remained the same from baseline (*Mdn* = 2), to six-months (*Mdn* = 2), to one-year (*Mdn* = 2), as such there were no statistically significant differences, $\chi^2(2) = 2.492$, $p = .288$.

2.4.3.4.2 Patient Transfer Task

The following section provides results of the Friedman tests conducted to determine variability in HRV measures obtained during the performance of the patient transfer task over a one-year period.

Patient transfer – head. A Friedman test was performed to determine if there were differences in MSK injury risk during performance of the patient transfer task while lifting at the head of the weighted manikin over a one-year period. Musculoskeletal injury risk remained the same from baseline (*Mdn* = 3), to six-months (*Mdn* = 3), to one-year (*Mdn* = 3), as such there were no statistically significant differences, $\chi^2(2) = 3.073$, $p = .215$.

Patient transfer – feet. A Friedman test was performed to determine if there were differences in MSK injury risk during performance of the patient transfer task while lifting at the feet of the weighted manikin over a one-year period. Musculoskeletal injury risk remained the same from baseline (*Mdn* = 3), to six-months (*Mdn* = 3), to one-year (*Mdn* = 3), as such there were no statistically significant differences, $\chi^2(2) = .143$, $p = .931$.

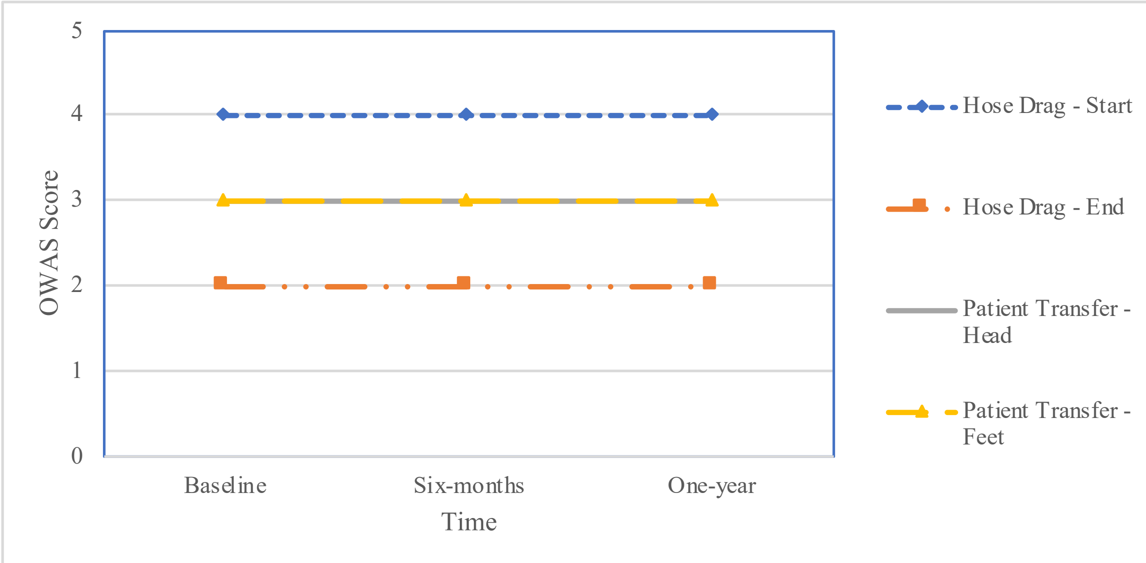

Figure 2.6. Median OWAS score indicating musculoskeletal injury risk associated with each task at each timepoint.

2.5 Discussion

The purpose of this study was to quantify TBFR's physiological response to physically demanding firefighting tasks as well as quantify their MSK injury risk during the performance of those tasks. Additionally, assessment of variability in the dependent variables over a one-year period allowed for the determination of whether physiological response and MSK injury changed over time. The findings of this study provide insights on firefighters' work health and impacts of cumulative load on firefighters' health. Findings suggest that firefighters' cumulative exposures and injury risk are high with no significant change over time although there appears to be change in physiological tolerance to task over time. The following section will further discuss the results and implications of this study.

2.5.1 Physiological Load

2.5.1.1 Heart Rate

Heart rate data collected during task performance was used to provide insights on the physiological load associated with each task. Higher working HR values are indicative of the physiological demands and level of physiological exertion required to perform the tasks (Romet & Frim, 1987). In order to better understand the impacts of task performance on physiological exertion, HR data were normalized as a percentage of participants' age-predicted maximum HR.

2.5.1.1.1 Hose Drag Task

During the performance of the hose drag task, participants were working at 64.7% to 69.6% of their APMHR across timepoints, indicating the task was performed at a moderate intensity (Tremblay et al., 2007). This intensity is expected as participants were instructed to treat the simulation as if they were approaching a garage fire with no life in danger. As such, participants were not performing the task at maximal effort as they might have in the case where the situation required more urgency. Under such circumstances, firefighters would typically reach 70%-80% of their APMHR within the first minute of firefighting and sustain a heart rate of 85%-100% of maximum throughout (Guidotti, 1992; Manning & Griggs, 1983).

Firefighters were instructed to perform the task identically across timepoints, however variability in HR during task performance was observed. Heart rate remains consistent at 64.7% at the baseline and six-month timepoints but increases to 69.6% of APMHR at the one-year timepoint. This change was statistically significant from the baseline to one-year timepoints. This may indicate that the firefighters are becoming deconditioned over time. Factors such as aging, decreased physical activity levels, and injuries may be contributing factors to the decline in physiological tolerance to the task over time (Fatisson, Oswald, & Lalonde, 2016).

2.5.1.1.2 Patient Transfer Task

During performance of the patient transfer task, participants were working at 55.6% to 58.7% of their APMHR during the performance lifts performed at both ends of the weighted manikin. This was observed across all time points. This suggests that the task was performed with light effort (Tremblay et al., 2007). These findings are expected as the task was performed in a short duration, requiring little aerobic exertion. The physiological load associated with the patient transfer task while lifting from the feet was slightly lower than while lifting from the head of the weighted manikin. This is an expected finding as participants are lifting less weight while lifting at the feet, therefore requiring less effort to perform the task.

2.5.1.2 Heart Rate Variability

Heart rate variability data collected during task performance was used to provide insights on participants' physiological tolerance to the simulated firefighting tasks and potential manifestations of physiological fatigue during task performance. Measures of physiological tolerance may elucidate manifestation of fatigue and firefighters' ability to regulate physiological response to various stressors (Kaikkonen et al., 2017). Higher HRV values are indicative of a heightened tolerance to the physiological demands of the tasks while lower HRV values are indicative of reduced tolerance (Shaffer et al., 2014). A low HRV is also associated with poor health outcomes and may provide insights on the manifestation of physiological fatigue (Shaffer et al., 2014). Results of this study display a trend that suggests that firefighters are developing an increased physiological tolerance to firefighting tasks (i.e., patient transfer tasks) as demonstrated by increases in HRV despite the increase in physiological load (HR) over one year. However, overall HRV is still low across all tasks and timepoints as HRV values below 100 ms are deemed to be maladaptive (Shaffer & Ginsberg, 2017). A low HRV suggests an increase in sympathetic activity of the autonomic nervous system (ANS) and is often observed with an increased HR, indicative of physiological or psychological stress (Kaikkonen et al., 2017).

2.5.1.2.1 Hose Drag Task

Overall, HRV during performance of the hose drag task is higher than HRV during the performance of the patient transfer task. This suggests that the high physiological demands of the hose drag task were eliciting an adaptive response (Shaffer et al., 2014) whereas the patient transfer task, requiring less exertion, required less of an adaptation to meet the demands of the task (Plews, Laursen, Kilding, & Buchheit, 2013). An additional possible explanation for the higher HRV observed during the performance of the hose drag task as compared to the patient transfer tasks is the effect of the order in which the tasks were performed. The more strenuous hose drag task was performed prior to the performance of the patient transfer tasks, and while participants were given a chance to recover between completion of tasks, a latency effect of hose drag task performance may be presenting during the performance of the patient transfer tasks.

2.5.1.2.2 Patient Transfer Task

The lowest HRV values observed during task performance appeared to be associated with the patient transfer task. Heart rate variability was lowest during the performance of the patient transfer task while lifting at the head of the weighted manikin. It is not unexpected that HRV during this task was lower than HRV observing while lifting at the feet of the manikin as there is a higher load associated with lifting at the head (heavier lift). Heart rate variability during task performance progressively increased from baseline through six-months to one-year with significant differences observed between baseline and one-year timepoints during both lifts. Despite the increase in HRV over time, overall HRV is low during performance of the patient transfer task as compared to the hose drag task. The lower HRV observed during the performance of a less demanding task suggests that there may be factors other than physiological load that are contributing to the reduced HRV observed. While the physiological load associated with the task is lower, there may be a higher psychological load associated with the patient transfer task. The patient transfer task simulates critical incidents (e.g., exposure to severe medical trauma) which may be causing participants to experience some of the psychological impacts of the task. Using different measures of HRV (e.g., frequency-domain measures) can provide more specific information on factors contributing to HRV.

Overall, HRV increases from baseline to one-year with the greatest increase from the six-month to one-year period where higher heart rate variability is associated with better health outcomes (Shaffer et al., 2014). Individuals with SDNN measures of HRV lower than 100ms are likely to have compromised health (Kleiger et al., 1987). Based on low heart rate variability during simulated firefighting tasks (*M* = 66.63 ms, *SD* = 8.17), there is a potential need for interventions designed to mitigate fatigue associated with demands of firefighting tasks. Furthermore, there is a known link between fatigue and MSK injury risk (Conrad et al., 1994) where higher HRV is associated with an adaptive response to an experienced stressor (Shaffer et al., 2014). These preliminary results suggest that cumulative firefighter work demands could lead to the manifestation of fatigue and ultimately increase the risk of MSK.

2.5.1.3 Musculoskeletal Injury Risk

2.5.1.3.1 Hose Drag Task

Results of the OWAS risk assessment tool indicated that firefighters are at high risk of incurring MSK injuries during performance of the hose drag task. This highest MSK injury risk was associated with the start phase of the task during which firefighters are retrieving the nozzle from the ground, starting from a standing position. Factors that contribute to this high risk for injury include bending and twisting postures of the spine, squatting and kneeling postures of the lower limb, and reaching postures associated with the upper limb. These high-risk postures in combination with the heavy loads imposed by turnout gear and SCBA worn by firefighters place them at high risk of incurring an MSK injury. Results of the OWAS risk assessment tool indicate that modifications need to be made to this task immediately in order to mitigate MSK injury risks associated with task performance.

The end phase of the hose drag task during which firefighters are discharging the hose while holding a stationary position was associated with a low risk of MSK injury. The static nature of this task allows firefighters to assume a stable position/ posture prior to discharging the nozzle and bracing the kickback force. There was some variability in the postures assumed by firefighters while performing this phase of the task. While some firefighters assumed a standing position, others discharged the nozzle from a kneeling position. Additionally, variability in upper limb postures was observed. Some participants kept the nozzle close to the torso while others had the arms flexed at the shoulders in front of them. In both cases participants generally maintained an upright trunk position, which is the likely contributor to the reduced injury risk associated with this phase of the hose drag task. While the postures associated with the end phase of the hose drag task do not need immediate modification, the task should be examined for modification of in the near future to reduce risk of MSK injury.

The postures associated with hose drag task performance remained consistent over the course of a year indicating that there was no change in the way firefighters performed the hose drag task at each time point. These consistent MSK injury risk scores expose firefighters to cumulative biomechanical loads that increase their risk of incurring MSK injuries in the near and immediate future.

2.5.1.3.2 Patient Transfer Task

Results of the OWAS risk assessment tool indicated that firefighters are at moderate risk of incurring MSK injuries during performance of the patient transfer task. Factors that contribute to the risk of MSK injury during performance of the patient transfer included bending of the spine during a squatting posture while carrying the loads imposed by the turnout gear worn as well as the weight of the manikin. Additionally, reaching with the arms to grasp the manikin may have played a role in the observed high-risk postures. Results of the OWAS risk assessment tool indicate that examination of postures is needed in the near future in order to mitigate MSK injury risks associated with patient transfer task performance.

The OWAS scores associated with the performance of the patient transfer task were the same for lifts performed at the head (heavy) and foot (light) ends of the weighted manikin. This is unexpected as the weight lifted while lifting from the head end of the manikin is higher than that lifted while lifting at the feet of the manikin. The heavier weight lifted while lifting at the head of the manikin is anticipated to have placed higher biomechanical loads on the spine that should result in a higher risk of MSK injury. A potential reason this difference in MSK injury risk is not reflected in the OWAS score may be the sensitivity of the tool to stratify MSK injury risk. Classification of the weight of the load handled in the postures associated with task performance fall into one of three categories within the OWAS risk assessment tool. More classification levels for the weight handled may provide a higher sensitivity to the accuracy of the MSK injury risk associated with different loads carried.

2.6 Conclusion

The purpose of this study was to quantify TBFR firefighters’ physiological response and risk of MSK injury during firefighting task performance and to assess whether these factors vary over time. The findings of this study suggest that firefighters' exposures to physiological load and MSK injury risk appeared to be high, compromising the health and safety of firefighters as a result of overexertion. While HRV increased over time, values were still consistently below healthy. Musculoskeletal injury risk associated with tasks remained consistent over time. The impacts of the biomechanically labourous nature of the tasks are known and were further supported by the results of this study. A finding of interest is the human-human interactive nature of the patient transfer tasks and the potential psychological strain imposed on firefighter during the performance of this task in addition to the physical strain. The findings of this study highlight the importance of considering these factors in the development of injury mitigation strategies for MSK injury risk, fatigue, and fatigue-mediated injuries. Comprehensive strategies that consider multiple injury risk factors are likely to be more effective at keeping firefighters safe on the fireground.

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Chapter 3:IDENTIFYING CRITICAL INCIDENT EXPOSURE AMONG THUNDER BAY FIRE RESCUE FIREFIGHTRS

3.1 Abstract

Firefighters are exposed to various factors associated with an increased risk of post-traumatic stress injury (PTSI). Critical incident exposure is one of the highest risk factors associated with PTSI. The objective of this study was to quantify critical incident exposure among Thunder Bay Fire Rescue (TBFR) firefighters. Critical incident exposure was measured using the 24-item Critical Incident Inventory (CII) developed to assess critical incident exposure among firefighters with a two-month point prevalence at each timepoint at three timepoints over 1-year (baseline (November 2017), six-months (May 2018), and one-year (November 2018)). Descriptive statistics for each subscale and total score at each time point were identified. Findings indicated that 94% of participants experienced at least one critical event at each timepoint. The most common critical event exposure recorded was direct exposure to blood and body fluids, responding to an incident involving one or two deaths, and removing a dead body or bodies. Study results suggest that TBFR firefighters experience call volumes with high critical incident exposure, multiple causalities, and incidents involving children; results further suggest PTSI exposure is high. These findings suggest TBFR firefighters require an intervention to mitigate impacts associated with critical incident exposure.

3.2 Introduction

Firefighters play a very important role in protecting the safety of our communities through fire suppression as well as providing emergency rescue and medical services. In addition to the high workload firefighters experience, there are various psychological factors that firefighters are exposed to that have impacts on their health. Firefighters have higher rates of injuries and illness than those in other occupations and often face risks of life-threatening injuries or death (Guidotti, 1992; Reichard, 2010). Additionally, firefighters are exposed to many psychological stressors while on the job. While firefighters experience the typical psychological stresses associated with other occupations (job satisfaction, autonomy, supervisor and peer group support, career advancement, etc.) they are also faced with other job-specific psychological stresses (Guidotti, 1992; Treaster & Burr, 2004). Fire-specific sources of job-related stress include (but are not limited to), anxiety induced by: alarms, personal safety, the safety of others, and social expectations (Guidotti, 1992).

Once on the fire ground, firefighters incur a high degree of personal risk through their occupational tasks, often running into an emergency situation that causes others to flee instinctively, due to the level of associated danger. These situations, (e.g. fire), are often unpredictable (Guidotti, 1992). In addition to their personal safety, firefighters are responsible for protecting the safety of others. Often through victim rescues, firefighters are subjected to what is anecdotally deemed to be the most stressful experience: that is, a failed rescue, especially that of a child (Guidotti, 1992). Through victim rescues, firefighters witness critical incidents such as gruesome injuries, pain, and strong emotion, ensuing a great deal of stress for firefighters.

The burden associated with such critical event exposures and the corresponding impact on firefighters' psychological health has been previously explored (Mitchell & Dyregrov, 1993; Weiss et al., 1995). The inconsistent findings within these studies on the relationship between exposure to critical events and negative psychological effects indicate a need for the development of a tool to assess this relationship. Monnier, Cameron, Hobfoll, and Gribble (2002) developed the Critical Incident Inventory (CII) to address this gap and assess the impact of critical incident exposure on psychological functioning.

The Critical Incident Inventory is a self-report questionnaire that was developed as a measure of the traumatic events that firefighters experience through their occupation (Monnier et al., 2002). The questionnaire encompasses a broad range of traumatic stressors that firefighters are likely to encounter, with some events more commonly experienced than others. Exposure to critical events during the performance of firefighting tasks has been found to have a negative effect on firefighters' psychological functioning (e.g., depressive symptoms and anger). There is evidence suggesting that the CII is an effective tool examining the impact of firefighters' exposure to stress on the job (Monnier et al., 2002).

Constant exposure to cognitive activity, mentally demanding tasks, and critical events over a long period of time has been shown to have adverse effects on psychological functioning such as emotional control (Monnier et al., 2002; Zhang & Yu, 2010). Furthermore, psychological functioning has been found to be strongly associated with the prevalence of fatigue (Kaikkonen et al., 2017). For example, psychological diagnoses including depression, anxiety, and emotional stress have been strongly associated with the prevalence of fatigue characterized by a reduced heart rate variability and experiences of weariness, reduced alertness, and reduced performance

(Chen, 1986; Zhang & Yu, 2010). These symptoms of fatigue lead to a decreased workplace productivity, decreased health, and increased accidents (Zhang & Yu, 2010).

Measuring psychological load associated with firefighter work, over various time points, provides insight on the cumulative effects of stressors and their impact on firefighters' health. However, previous studies assessing these demands have been cross-sectional, measuring physical and psychological demands at one point in time. While this work has been foundational in improving the understanding of the burden of injuries in firefighters, it poses limitations for understanding the cumulative effects of these demands.

3.2.1 Research Objective

The purpose of this study was to quantify critical incident exposure among Thunder Bay career firefighters and determine if critical incident exposure changed over a one-year period.

3.3 Methods

3.3.1 Study Design

This study was a cohort study with repeated measures in which data on firefighters' critical incident exposure was collected at three time points: Baseline-November 2017; 6-months – June 2018 and 12-months – November 2018.

3.3.2 Participants

A sample of 40 participants was recruited from the Thunder Bay Fire Rescue (TBFR) at the baseline timepoint, inclusive of active-duty (n = 32) and recruit (n = 8) firefighters between the ages of 23 and 58 years old (SD = 8.7). Participants included male (n = 39) and female (n = 1) firefighters.

3.3.3 Data Collection

Critical incident exposure was quantified using the Critical Incidents Inventory Questionnaire (Monnier et al., 2002) (Appendix B). This is a 24-item questionnaire containing six subscales. The Critical Incident Inventory (CII) is a self-report questionnaire that was developed as a measure of the traumatic events that firefighters experience through their occupation (Monnier et al., 2002). The questionnaire encompasses a broad range of traumatic stressors that firefighters are likely to encounter. Exposure to critical events during the performance of firefighting tasks has been found to have a negative effect on firefighters' psychological functioning (e.g., depressive symptoms and anger). The psychometric properties of the CII are well documented among firefighters ($r = .36$, $p < .05$, n=150) (Monnier et al., 2002). There is evidence suggesting that the CII is an effective tool examining the impact of firefighters' exposure to stress on the job (Monnier et al., 2002).

The questionnaire required participants to respond to the frequency at which the 24 events had occurred in the past two months. The events fall within the six subscales of trauma to self, victims known to fire-emergency worker, multiple casualties, incidents involving children, unusual or problematic tactical operations, and exposure to severe medical trauma. Participants noted whether they had or had not experienced each event in the past two months, had an occurrence "one time", "two times", or "three or more times". A score of 0, 1, 2, or 3 was assigned to each item respectively which denoted exposure level.

3.3.3.1 Critical Incident Inventory Data Processing

The questionnaire outcome was then scored by summing scores for each item. There is some evidence of convergent validity of the CII, with scales being significantly related to psychological functioning ($r = .218$, $p < .05$, n=150) (Monnier et al., 2002).

3.3.4 Statistical Analysis

Descriptive statistics (mean, standard deviation, minimum, and maximum values) were produced for demographic data. Additionally, descriptive statistics (median and range) were produced for total CII scores as well as each subscale. In order to determine if there is variability in total critical incident exposure as well as exposure within each subscale over the one-year period, a series of Friedman tests were conducted. Differences in CII scores (dependent variable) were assessed across the three levels of the independent variable, time (baseline, 6-months, 1-year). A Bonferroni post-hoc analysis was performed to better understand the specific time points at which CII scores differ.

3.4 Results

3.4.1 Demographics

The participant sample recruited for this study consisted of male (n = 39) and female (n = 1) new recruit and active-duty firefighters. Participation varied over the one-year period with an 8% attrition rate at the six-month time point (n = 36) and a 10.9% attrition rate by the one-year time point (n = 35). However, recruit firefighters' baseline data was not included in analysis as they would have had no exposure at the time of study enrolment. Therefore, only data from active duty firefighters was included in baseline analysis. Participants were an average age of 37 (+/- 8.7) years old at recruitment and had been firefighting for a mean of 9.2 (+/- 8.0) years. A full summary of participant demographics over each time point can be found in Table 1.

Table 3.1

Descriptive statistics for demographic data

	Mean	Standard Deviation	Minimum	Maximum
Baseline[a]				
Age	37.0	8.7	23	58
Yrs. Of Service	9.2	8.2	.42	29
Six-months[b]				
Age	37.4	9.0	24	58
Yrs. Of Service	9.5	8.3	.5	30
One-year[c]				
Age	38.7	8.9	24	59
Yrs. Of Service	10.6	8.3	1	30

[a]*n* = 32. [b]*n* = 36. [c]*n* = 35.

3.4.2 Total Critical Incident Exposure

3.4.2.1 Descriptive Statistics

Critical incident exposure was quantified at each time point (baseline, 6-months, and 1-year). The median CII scores and range experienced by participants over a two-month period at baseline, six-months, and one-year are presented in Table 2. Critical incident exposure range is high with higher exposure to critical events at the baseline and one-year timepoints. Baseline exposure indicates that firefighters typically experienced seven critical events over a two-month period. The number of events experienced over a two- month period drops slightly, to five, at the 6-month timepoint with exposures returning to seven at the one-year timepoint.

Table 3.2

Critical Incident Inventory Score Descriptive Data

	Median	Range
Baseline	7	40
Six-months	5	19
One-year	7	32

Note. Data reported as number of incidents

3.4.2.2 Inferential Statistics

A Friedman test was conducted to determine if there were differences in total CII score over a one-year period. Critical incident exposure decreased from baseline (*Mdn* = 7), six-months (*Mdn* = 5), and increased at one-year (*Mdn* = 7). The differences were not statistically significant, $\chi_2(2) = 4.092$, $p = .129$.

3.4.3 Critical Incident Exposure Subscales

3.4.3.1 Descriptive Statistics

The following section provides descriptive statistics for exposure to critical incidents within each subscale. Critical incident exposure to events within each of the six subscales is further presented in Table 3.

Table 3.3

Descriptive Data for Critical Incident Inventory Subscales

	Trauma to Self	Victims Known to Fire-Emergency Worker	Multiple Casualties	Incidents Involving Children	Unusual or Problematic Tactical Operations	Exposure to Severe Medical Trauma
Baseline						
Median	2	0	2	0	1	0
Range	11	6	9	5	8	9
Six-months						
Median	1	0	2	0	0	0
Range	5	3	6	6	4	2
One-year						
Median	1	0	2	0	1	1
Range	8	4	6	4	7	6

Note. Data reported as number of incidents.

Exposure to each of the events listed in the CII experienced by participants is represented as percentages for each time point in Table 4. The most frequently experienced incidents across time points were direct exposure to blood and body fluids, incidents involving one or two deaths, removing a dead body or bodies, and incidents requiring police protection while on duty.

Table 3.4

Percentages of TBFR Fire-Emergency Workers' Response to Critical Incident Inventory Items

CII Item	One time (%)	Two or more times (%)	None (%)
	T1; T2; T3	T1; T2; T3	T1; T2; T3
Trauma to Self			
1. Serious line of duty injury to self.	0; 0; 5.7	0; 0; 0	100; 100; 94.3
2. Threat of serious line of duty injury or threat of death to self (that did not result in actual serious injury).	6.5; 2.9; 8.6	6.5; 5.9; 8.6	87.1; 91.2; 82.9
19. Incident necessitating search or rescue involving serious risk to yourself.	6.3; 12.1; 14.3	6.3; 3.0; 2.9	87.5; 84.8; 82.9
22. Direct exposure to extremely hazardous materials.	15.6; 5.9; 5.7	9.4; 0; 2.9	75.0; 94.1; 88.6
23. Direct exposure to blood and body fluids.	25.8; 11.8; 28.6	45.2; 26.5; 28.6	29.0; 61.8; 42.9
Victims Known to Fire-Emergency Worker			
3. Line of duty death of fellow emergency worker.	0; 0; 0	0; 0; 0	100; 100; 100
4. Serious line of duty injury to fellow emergency worker (that did not result in death).	0; 2.9; 8.6	0; 0; 0	100; 97.1; 91.4
5. Threat of serious line of duty injury or threat of death to fellow emergency worker (that did not result in actual serious injury or death).	12.5; 0; 20.0	6.3; 8.8; 11.4	81.3; 91.2; 68.6
6. Suicide or attempted suicide by fellow emergency worker.	3.1; 2.9; 0	0; 0; 0	96.9; 97.1; 100
12. Victim(s) known to you.	15.6; 14.7; 8.6	6.3; 2.9; 2.9	78.1; 82.4; 82.9
Multiple Casualties			
7. Responded to incident involving three or more deaths.	3.2; 0; 0	6.5; 0; 0	90.3; 100; 100
8. Responded to incident involving one or two deaths.	31.3; 20.6; 31.4	46.9; 20.6; 45.7	21.9; 58.8; 22.9
9. Responded to incident involving multiple serious injuries (three or	18.8; 8.8; 17.1	21.9; 14.7; 14.3	59.4; 76.5; 68.6

more victims sustained serious injuries).			
Incidents Involving Children			
12. Incident involving serious injury or death to children.	15.6; 14.7; 8.6	6.3; 2.9; 2.9	78.1; 82.4; 88.6
13. Incident involving severe threat to children (that did not result in actual serious injury or death to children).	22.6; 8.8; 8.6	9.7; 2.9; 2.9	67.7; 88.2; 82.9
Unusual or Problematic Tactical Operations			
10. Incident requiring police protection while on duty.	22.6; 20.6; 25.7	19.4; 5.9; 14.3	58.1; 73.5; 60
11. Verbal or physical threat by public while on duty (that did not result in police protection).	12.5; 17.6; 11.4	15.6; 2.9; 8.6	71.9; 79.4; 80
15. Failed mission after extensive effort.	15.6; 8.8; 11.4	3.1; 0; 5.7	81.3; 91.2; 82.9
16. Critical (negative) media interest.	16.1; 5.9; 8.6	12.9; 5.9; 2.9	71.0; 88.2; 80
21. Use of deadly force by police at an incident.	0; 0; 2.9	3.1; 0; 0	96.9; 100; 97.1
24. Critical equipment failure or lack of equipment in any of the above situations.	6.5; 5.9; 2.9	0; 0; 0	93.5; 94.1; 97.1
Exposure to Severe Medical Trauma			
17. Close contact with burned or mutilated victim	9.4; 8.8; 37.1	6.3; 0; 14.3	84.4; 91.2; 48.6
18. Removing dead body or bodies.	16.1; 8.8; 28.6	22.6; 11.8; 8.6	61.3; 79.4; 48.6
20. Prolonged extrication of trapped victim with life-threatening injuries.	6.3; 2.9; 5.7	6.3; 0; 2.9	87.5; 97.1; 91.4

Note. Exposure to each event within each subscale is reported as a percentage for each time point above. Exposure at each time point is separated by a semicolon. T1: Baseline measure; T2: Six-months; T3: One-year.

3.4.3.2 Inferential Statistics

The following section provides results of a series of Friedman tests conducted to determine whether exposure to critical events within each subscale varied over time. The Friedman test was selected to assess differences in CII subscale scores over time as the data is non-continuous.

3.4.3.2.1 Trauma to Self

A Friedman test was conducted to determine if there were differences in critical exposure to events within the Trauma to Self subscale over a one-year period. Trauma to Self decreased from baseline (*Mdn* = 2), to six-months (*Mdn* = 1), and one-year (*Mdn* = 1), but the differences were not statistically significant, $\chi 2(2) = 5.738$, $p = .057$.

3.4.3.2.2 Victims Known to Fire-Emergency Worker

A Friedman test was performed to determine if there were differences in critical exposure to events within the Victims Known to Fire-Emergency Worker subscale over a one-year period. Critical incident exposure to victims known remained the same at all three timepoints with no exposure (*Mdn* = 0). As such the differences were not statistically significant, $\chi 2(2) = 3.724$, $p = .155$.

3.4.3.2.3 Multiple Casualties

A Friedman test was performed to determine if there were differences in critical exposure to events within the Multiple Casualties subscale over a one-year period. Exposure to multiple casualties remained the same at all three timepoints (*Mdn* = 2). The differences across timepoints were not statistically significant, $\chi 2(2) = 1.000$, $p = .607$.

3.4.3.2.4 Incidents Involving Children

A Friedman test was performed to determine if there were differences in critical exposure to events within the Incidents Involving Children subscale over a one-year period. Exposure to incidents involving children remained the same at all three timepoints with no exposure (*Mdn* = 0). As such the differences were not statistically significant, $\chi 2(2) = 4.964$, $p = .084$.

3.4.3.2.5 Unusual of Problematic Tactical Operations

A Friedman test was performed to determine if there were differences in critical exposure to events within the Unusual or Problematic Tactical Operations subscale over a one-year period. Exposure to unusual or problematic tactical operations decreased from baseline (*Mdn* = 1), to six-months (*Mdn* = 0), and one-year (*Mdn* = 1), but the differences were not statistically significant, $\chi 2(2) = 1.738$, $p = .419$.

3.4.3.2.6 Exposure to Severe Medical Trauma

A Friedman test was performed to determine if there were differences in critical exposure to events within the Exposure to Severe Medical Trauma subscale over a one-year period. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Exposure to severe medical trauma was statistically significantly different at the different time points, $\chi 2(2) = 6.493$, $p < .05$. Post hoc analysis revealed statistically significant differences in exposure from six-months (*Mdn* = 0) to one-year (*Mdn* = 1) ($p < .045$), but not baseline to one-year (*Mdn* = 1) or baseline to six-months (*Mdn* = 0).

3.5 Discussion

The purpose of this study was to quantify and assess changes in TBFR's exposure to critical incidents over a one-year period. The findings of this study provide insights on firefighters' work health and impacts of critical incident exposure on firefighters' psychological health. Findings suggest that firefighters' exposures to critical incidents is high with no significant change over time. The following section will further discuss the results and implications of this study.

Analysis of the CII administered to quantify TBFR firefighters' exposure to critical events revealed that two-month point prevalence exposure was high at each of the timepoints with no significant change over time. While the difference in critical incident exposure across timepoints is not significant, CII scores appear to be higher at the baseline and one-year timepoints. This suggests that there may be a seasonal effect on call volume and types of incidents responded to during those calls. An additional interesting trait of the CII data is the high range in number of incidents experienced by firefighters. This range indicates that some participants had numerous exposures to traumatic events. Thunder Bay Fire Rescue firefighters typically work eight shifts per month. Therefore, over the two-month point prevalence of the CII, firefighters worked 16 shifts. This indicates that some firefighters experienced up to three critical events in one shift. These results suggest that TBFR firefighters consistently experience call volumes with high critical incident exposure. These high exposures can have impacts on firefighters' experience of PTSIs (Haugen et al., 2012). A closer look at the most frequently experienced events indicated that 94% of participants experienced at least one critical event at each time point. The most frequently experienced incidents across timepoints were direct exposure to blood and body fluids, incidents involving one or two deaths, removing a dead body or bodies, and incidents requiring police protection while on duty.

Previous research has suggested that exposure to critical events has effects on firefighters' mental health (Corneil, Beaton, Murphy, Johnson, & Pike, 1999; Monnier et al., 2002; Wagner, McFee, & Martin, 2010). Exposure to critical incidents has been found to have negative outcomes on psychological functioning though expression of anger and experiences of dysphoria (Monnier et al., 2002). Further, critical incident exposure may have impacts on the experience of PTSD and self-reported PTSS (Corneil et al., 1999).

Firefighters' high exposure to physical and psychological loads can result in cumulative overload effects. The cumulative effects of stressors have a known impact on a decrease in HRV that is indicative of the potential manifestation, if not presence, of fatigue. Additionally, firefighters' exposure to critical events also increases their of post-traumatic stress injuries, impacting their mental health (Corneil et al., 1999; Donnelly & Bennett, 2014). The effects of critical incident exposure on psychological health may also have further impacts on firefighters' physical health as well. A decreased HRV that is often observed in individuals experiencing PTSIs is associated with poor health outcomes and increases individuals' risk of experiencing a myocardial infarction (Goldberg et al., 2013; Shaffer & Ginsberg, 2017). Furthermore, there is a known link between fatigue and psychological demands and a heightened risk of MSK injury (Conrad et al., 1994). Identifying critical incident exposure among firefighters will provide additional insights into psychological demands associated with the job to allow for the development of interventions to mitigate the negative outcomes associated with high exposures.

Results of the current study suggest that TBFR firefighters' critical incident exposure is high compared to critical incident exposure data collected from other Canadian firefighters (MacDermid et al., 2019). This high exposure furthers suggests that their risk of PTSI may also be high. Further studies are required to better understand TBFR firefighters' PTSI rates. Findings of this study suggest that TBFR firefighters require an intervention to mitigate impacts associated with critical incident exposure.

3.6 Conclusion

Thunder Bay Fire Rescue Firefighters have high exposures to critical incidents while on duty. The high exposures to traumatic events remain consistent over a one-year. Critical incident exposure is known to have adverse effects on firefighters' mental health and psychological functioning (Corneil et al., 1999; Monnier et al., 2002). Findings of this study suggest that TBFR firefighters' risks to PTSIs are high which may have implications on other aspects of firefighters' work-health (Conrad et al., 1994). There is an evident need for targeted mental health interventions in firefighters to ensure their health and safety both on and off the fireground, the safety and well-being of our communities depend on the wellbeing of our emergency service personnel.

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Chapter 4:DISCUSSION

The studies included in this thesis provide a quantification of various factors related to firefighters' work-health. The results of these studies provide insights into the physiological and psychological demands associated with strenuous firefighting job tasks. The overarching goal of this research is to use the gathered data to inform the development of evidence-based injury prevention strategies that take psychological and physical injury risk factors into consideration. This discussion chapter will summarize the overall findings of the research and provide elaborations on the limitations and future directions.

4.1 Summary of Findings

The interrelationship between physical load and exposure to traumatic events and how they might affect fatigue and MSK injury risk are poorly understood among first responders including firefighters. Findings suggest that TBFR firefighters' psychological and physical exposures are high. There was no significant change in HRV during the performance of the hose drag task over time, while HRV significantly increased from baseline to one-year during performance of the patient transfer tasks. This finding suggests that participants may have adapted to the demands of the of the patient transfer task over time. While this increase was observed, HRV values were still below healthy ranges during the performance of all tasks at all time points. As formerly mentioned, a higher HRV is associated with better health outcomes while individuals with SDNN measures of HRV lower than 100ms are likely to have compromised health (Shaffer et al., 2014).

Additionally, the lowest HRV values were observed during the performance of the patient transfer tasks despite the hose drag task being more physiologically demanding (as determined by HR as a % of APMHR). A possible reason for this reduced HRV may be the higher exposures to critical incidents involving the removal of dead bodies, responding to incidents involving multiple serious injuries, and responding to incidents involving one or two deaths. The simulation of tasks resembling the frequently experienced critical incidents may have a psychological impact manifesting through the observed decrease in HRV. Overall, HRV appears to increase from baseline to one-year, despite little variance in the physiological response to the demands of the task, suggesting the potential use of adaptive strategies to coping with the physiological and psychological occupational stressors over time.

Musculoskeletal injury risk remained unchanged over a one-year period which may be a result of the consistently high psychological exposures and low HRV during task performance. Heart rate variability, CII, and MSK injury data collected from the TBFR firefighters suggest a need for interventions to mitigate the impact psychological and physical factors on overall health (i.e., mental and physical health). Furthermore, there is a known link between fatigue and MSK injury risk (Conrad et al., 1994). These preliminary results suggest that critical incident exposure could lead to the manifestation of psychological fatigue and ultimately increase the risk of MSK injuries. Further research should strive to incorporate the use of frequency-domain measures of HRV for more specific insights into malfunction of various systems. The high frequency band of frequency-domain measures is often observed for determining the presence of chronic psychological fatigue (Salahuddin et al., 2007). This will allow for stronger inferential statistical testing to better understand the relationship between critical incident exposure and psychological fatigue.

4.2 Limitations

There are a few limitations of this study with regards to the validity and reliability of measures, sample size, and analysis. The primary limitation of this study is the use of digital cameras for a marker-less observation of postures. Limitations of the use of this tool is furthered with participants equipped in full bunker gear as joints and body segments are not as clearly visible. While postural analysis using video inputs in Dartfish has previously been found to produce acceptable levels of reliability in a firefighting context and validity, this was only done for lower extremity (trunk, hip, and knee) postures (Ceseracciu, Sawacha, & Cobelli, 2014; Sinden & MacDermid, 2016). The limitation with regards to video analysis used in this study is the collection of video data in a single plane of motion. For the purpose of this study, postural analysis was captured in the sagittal plane only. This fails to capture joint angle measurements of segments that move in multiple planes. This limitation is not likely to have a great impact on the stratification of injury risk in this study as specific joint angles are not required for input into the OWAS risk assessment tool. The collection of video and video analysis using Dartfish will allow for support to the subjective observation of joint angle ranges that will be input into OWAS for analysis of injury risk.

There are additional limitations imposed by the use of the OWAS risk assessment tool for understanding MSK injury risk. The OWAS is an observational risk assessment tool that is used to quantify the biomechanical basis of MSK injury. While other factors (e.g., psychological and physiological), in addition to biomechanical factors, play a role in MSK injury causation, the OWAS does not take these factors into consideration in quantifying injury risk. The results of this thesis may provide necessary information that can be used for the development of comprehensive MSK injury risk assessment tools.

Using a time-domain analysis method for analysis of HRV data is another limitation of this study. As previously mentioned, a frequency-domain method for analysis of HRV data is more optimal than a time-domain method. This is because frequency-domain methods provide a more detailed description of activity at various physiological and nervous pathways that innervate the heart. Frequency-domain methods allow for more specific insights into malfunction of various systems. However, the validity of this information is diminished when the duration of HRV measures are shorter than 1 minute (Shaffer & Ginsberg, 2017). For ultra-short term (≤ 1 minute) recordings of HRV, various time-domain measures are strongly correlated with various frequency-domain measures. The high frequency band (0.15-0.4 Hz) of frequency-domain measures is often observed for determining the presence of chronic central (mental) fatigue (Salahuddin et al., 2007). The time-domain SDNN measure is strongly correlated to ultra-low, very low, and low frequency band measures and provides insights on SNS and PNS activity (Shaffer & Ginsberg, 2017). An additional limitation of the use of this data was that participants' true resting HRV values were not collected prior to task performance. Understanding how measures during task performance varies from resting has the potential to provide more detailed insights on the effects of the task on HRV. Future studies should consider collecting true resting values for comparative analyses.

Additionally, the CII examines critical incident exposures over a two-month period. This restricts the range and number of incidents that firefighters could report on. However, the two-month point prevalence provides valuable insights on potential seasonal effects on exposure to critical events. Future studies should consider testing other time points to better identify changes in critical incident exposure at various timepoints and compare exposures (and potential seasonal effects) among different firefighting populations (explore locale impacts). It is important to note that administering the CII at multiple timepoints may expose firefighters to further psychological effects associated with recalling traumatic events (Monnier et al., 2002) and as such, efforts should be incorporated to mitigate such risks. However, a broader point prevalence has the potential to increase the chance of detecting effects (Kazdin, 1992).

4.3 Potential Implications

A unique aspect of this research is the observation of firefighter work health over time, with data collection occurring at three different time points. This will allow for an improved understanding of changes in firefighter work health over time which is unknown in the literature. In addition, findings of this research may potentially provide insights on factors that impact firefighters' health. The overarching goal of this research is to be able to use these findings to develop multi-dimensional injury prevention strategies that can be implemented in the Thunder Bay fire service. This study has provided additional information regarding the need, as determined by risk stratification and critical incident exposure, for development of both physical and psychological strategies. Results of this study inform the type of interventions needed for the prevention of MSK and posttraumatic stress injuries (PTSIs) based on injury risk and exposure to critical incidents. The following section provides an explanation of the potential injury prevention strategies through dissemination of research findings and development of educational tools for firefighters.

4.4 Proposed Knowledge Translation Strategy

This thesis uses an integrated knowledge translation approach where the primary knowledge users (i.e., TBFR and TBPFFA) are involved in both the design, implementation and dissemination of the research findings. This approach was informed by the Knowledge-to-Action framework which ensures that research outcomes are contextually relevant and ready for uptake (Graham et al., 2006).

Dissemination of research findings allows for the reach of knowledge on an organizational and individual level for greater impact. As previously stated, one of the goals of this research is to inform the development of injury prevention strategies to reduce the prevalence and risk of MSK injuries and PTSIs, keeping firefighters safe in hopes of improving their quality of life. The research findings will be presented to policymakers and stakeholders for the development of health and safety programs / information sessions through research days supported by both TBFR and TBPFFA. Furthermore, one of the features within the Dartfish movement analysis software allows for annotations of videos to provide feedback on high risk postures and recommendations for safer performance of the task. These annotations and feedback may be shared with individuals to allow visualization of safer task performance. Furthermore, the results of this study will be written into lay summaries for presentation to firefighters. Additional ways the results of this study will be disseminated is through presentations at research conferences as well as through manuscripts written for publication in peer-reviewed journals. Sharing the findings of this study through various educational formats may potentially reduce risk and incidence of injuries both on and off the fire ground.

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Appendix A

Participant Demographics Form

Date: ____/____/_______
dd mm yyyy

ID Code: ___________

Participant Demographics Form

Sex / Gender:

Age: _____

Date of Birth: ___/___/___
(dd/mm/yyyy)

Height: _____ft/inch or cm

Weight: _____ kg or lbs

Number of years as a firefighter: ___________

Job Title / Rank: _________________________________

Appendix B

Critical Incident Inventory Questionnaire

Date: ____/____/________ ID Code: ___________
dd mm yyyy Time: Baseline 6M 12M

Critical Incident Inventory (CII)

Instructions: Indicate the number of times each event has occurred in the **past 2 months**.

Questions	One time	Two Times	Three or more times	None
1. Serious line of duty injury to self.				
2. Threat of serious line of duty injury or threat of death to self (that did not result in actual serious injury).				
3. Line of duty death of a fellow emergency worker.				
4. Serious line of duty injury to fellow emergency worker (that did not result in death).				
5. Threat of serious line of duty injury or threat of death to fellow emergency worker (that did not result in actual serious injury or death).				
6. Suicide or attempted suicide by fellow emergency worker.				
7. Responded to incident involving three or more deaths.				
8. Responded to incident involving one or two deaths.				
9. Responded to incident involving multiple serious injuries (three or more victims sustained serious injuries).				
10. Incident requiring police protection while on duty.				
11. Verbal or physical threat by public while on duty (that did not result in police protection).				
12. Incident involving serious injury or death to children.				
13. Incident involving severe threat to children (that did not result in actual serious injury or death to children)				
14. Victim(s) known to you.				
15. Failed mission after extensive effort.				
16. Critical (negative) media interest.				
17. Close contact with burned or mutilated victim.				
18. Removing dead body or bodies.				
19. Incident necessitating search or rescue involving serious risk to yourself.				
20. Prolonged extrication of trapped victim with life-threatening injuries.				
21. Use of deadly force by police at an incident.				
22. Direct exposure to extremely hazardous materials.				
23. Direct exposure to blood and body fluids.				
24. Critical equipment failure or lack of equipment in any of the above situations.				