Applying the Allostatic Load Model to Investigate the Biological Embedding of Psychosocial Stress in Firefighters

by

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A thesis

presented to the University of Waterloo

in fulfilment of the

thesis requirement for the degree of

Doctor of Philosophy

in

Public Health and Health Systems (Work and Health)

Waterloo, Ontario, Canada, 2022

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

The funding support for this research work was provided by the Occupational Health and Safety (OHS) Futures Grant provided by the Government of Alberta, which was granted to Dr John Mielke and co-investigator Dr Philip Bigelow.

Somkene Igboanugo (SI) is the sole author of chapters 1, 2, 4, and 9, which were written under the supervision of Dr John Mielke and were not intended for publication. The remaining parts of the thesis consist of five chapters either already published, or intended for publication. Therefore, the exception to sole authorship of material are as follows:

Research presented in chapters 3 and 8

Both research works were conducted at the University of Waterloo by SI under the supervision of Dr John Mielke. For chapter three, SI conceived the idea of the project and prepared the manuscript; Dr Mielke and Dr Bigelow provided constructive feedback and helped edit the manuscript.

Chapter 3 Citation:

Igboanugo S, Bigelow P, & Mielke J. The Allostatic Load Model: A Theoretical Framework For Investigating The Multi-Systemic Impact Of Chronic Work-Related Psychosocial Stress Exposure Among Firefighters.

For chapter eight, SI, Dr John Mielke, and Dr Phil Bigelow contributed to the study design. SI and Dr Mielke oversaw participant recruitment. SI and research interns Claire

O'Connor, Dana Ghanem, and Tara Behroozian performed data collection by collecting, transporting, and storing the data. Data analysis was conducted by SI and Dr Ashok Chaurasia in consultation with Dr Mielke. SI wrote the draft manuscript, to which all co-authors contributed their input.

Chapter 8 Citation:

Igboanugo S, Chaurasia A, Bigelow P, & Mielke J. An Investigation Into The Relationship Between Psychosocial Stress And Allostatic Load In A Sample Of Canadian Firefighters During The Covid-19 Pandemic.

Research presented in chapter 5

The research work was conducted at the University of Waterloo by Somkene Igboanugo under the supervision of Dr John Mielke. SI designed the study with consultation from Claire O'Connor and Dr John Mielke. SI designed the search strategy, while Claire O'Connor and Osama Zitoun contributed to data collection. Dr Reza Ramezan designed the analytical method to analyse data while SI performed the data analysis and drafted the manuscript. All co-authors contributed to editing the manuscript before it was submitted for peer-review to the Journal *Psychophysiology* on July 28, 2022.

Chapter 5 Citation:

Igboanugo S, O'Connor C, Zitoun O, Ramezan R, & Mielke J. A Systematic Review Of Hair Cortisol In Healthy Adults Measured Using Immunoassay Methods: Proposed Reference Values For Research And Methodological Considerations.

Research presented in chapter 6

The research work was conducted at the University of Waterloo by SI under the supervision of Dr John Mielke. SI and Dr John Mielke conceived the study idea and contributed to the study design. SI and Dr Mielke conducted data collection and analysis and prepared the manuscript. Dr Phil Bigelow provided constructive feedback on the study design and edited the manuscript.

Chapter 6 citation:

Igboanugo, S., Bigelow, P. L., & Mielke, J. G. (2021). Health outcomes of psychosocial stress within firefighters: A systematic review of the research landscape. *Journal of Occupational Health*, *63*(1), e12219.

Research presented in chapter 7

The research work was conducted at the University of Waterloo by SI under the supervision of Dr John Mielke. SI, Dr John Mielke and Dr Phil Bigelow contributed to the study design. SI and Dr Mielke oversaw participant recruitment. SI and research intern Yue Lai-Zhao performed data collection. Data analysis was conducted by SI and Dr Ashok Chaurasia in consultation with Dr Mielke. SI wrote the draft manuscripts, to which all co-authors contributed their input during the editing stage.

Chapter 7 citation:

Igboanugo, S., Chaurasia, A., Bigelow, P. L., & Mielke, J. G (2022). Biological embedding of psychosocial stressors within a sample of Canadian firefighters: an exploratory analysis. *Journal of Occupational and Environmental Medicine*, 10-1097.

Abstract

Overview

Psychosocial factors are recognised as a significant source of stress in the workplace, and long-term exposure to such stressors may increase chronic disease risk through physiological wear and tear quantified by an individual's "allostatic load" (AL). Given that firefighters are critical to public safety, I investigated whether the duty-related psychosocial stressors they experience could affect their long-term health and wellbeing by causing increased levels of allostatic load.

Objectives

I began by consolidating information on work-related psychosocial stressors and related health consequences in firefighters by systematically reviewing the current literature. Next, I applied the allostatic load model, a comprehensive multi-systemic measure of cumulative stress impact, to elucidate the underlying mechanism linking psychosocial stressors to adverse health outcomes. Specifically, the relationship between a firefighter's perceived psychosocial stress and their AL was investigated cross-sectionally and longitudinally. In addition, the potential influence of specific demographic factors (e.g., age and length of service) and psychosocial resources (e.g., social support) on the psychosocial stress-AL (PS-AL) model was explored. Finally, I sought to determine the prevalence of COVID-19-related pandemic stress in this group and its effect on the investigated association.

Methods

First, a systematic review and meta-analysis of the literature on hair cortisol concentration (HCC) was completed to determine a normal reference value/range in healthy adults as part of the methodological recommendations for the thesis. Second, a systematic review of studies reporting psychosocial stressors and their related health outcomes experienced by firefighters was completed using the MEDLINE, PsychInfo, and CINAHL databases. Third, active firefighters were recruited from Waterloo Fire Rescue to investigate the PS-AL relationship. Data collection took place in two phases, a baseline and a follow-up session. In both phases, firefighters provided demographic and health-related information together with subjective assessments of their work-related stress experiences. Additionally, they provided anthropometric and physiological data representing stress-sensitive features of the neuroendocrine and cardiometabolic systems (for example, hair cortisol, heart rate variability, and lipid biomarkers).

Correlational analysis was used in the cross-sectional study to explore associations between key demographic, health, and physiological variables. In addition, a linear regression analysis was used to examine the relationship between psychosocial stress and allostatic load and to investigate the potential modifying effect of social support. Finally, a linear mixed-effect model was applied for the longitudinal analysis to explore the effect of psychosocial stress on allostatic load over time (baseline and follow-up), while accounting for the influence of age, social support, and COVID-19-related stress over the same period.

Results

An HCC reference value of 60.51 pg/mg was determined, and an upper limit (i.e., mean plus two standard deviations) for HCC for healthy adults was set at 241.28 pg/mg. For the systematic review, twenty-nine studies met the inclusion criteria. Firefighters identified a range of unique psychosocial stressors, such as interpersonal conflict and organisational fairness concerns. In addition, these stressors were significantly linked to various adverse health outcomes broadly grouped into six areas: depression-suicidality, non-depressive, mental health problems, burnout, alcohol use disorders, sleep quality, physiological parameters and somatic disorders.

The empirical data from the cross-sectional analysis revealed an association between work-related psychosocial stress and allostatic load, but the relationship did not reach the threshold for statistical significance. Interestingly, a firefighter's age significantly predicted allostatic load. In addition, the availability of social support displayed an inverse association with stress (i.e., firefighters who perceived more social support felt less stress than those who did not).

The longitudinal analysis of the relationship between psychosocial stress and AL revealed that, after accounting for age, social support, and Covid-related stress, a firefighter's perceived general-life stress at baseline was significantly associated with an increase in allostatic load after a year (95% CI: 0.01, 0.19; $p = 0.04$). However, work-related psychosocial stress at baseline did not meet the significance threshold. Moreover, although 48% of participants reported COVID-19-related stress, which was positively associated with general life stress experience, it played no significant role in the psychosocial stress-AL relationship.

Conclusion

Our findings reveal unique psychosocial stressors prevalent within firefighting and how these stressors may progressively affect health and wellbeing. In addition, the results indicate the continued importance of health-promotion interventions within this professional group. Although the study revealed more informative trends than definitive relationships, we believe that the AL model shows promise as a valuable tool for monitoring and preventing the cumulative health consequences of psychosocial stress among firefighters.

Acknowledgements

I want to acknowledge my committee members for their immeasurable support throughout this journey. First, Dr Ashok Chaurasia, thank you for taking time off your hectic schedule to provide expert statistical support and invaluable advice on navigating academia and life. Dr Peter Hall, I appreciate your constructive criticism, suggestions, and recommendation throughout this journey. You were quick to offer guidance whenever needed, and I am genuinely grateful.

Dr Phil Bigelow, thank you for the support and guidance. From the start of my Master's program to date, your expert contribution has been instrumental in completing my program and this project. In addition, I am grateful for all the opportunities you provided for me and, most importantly, the opportunity to apply my research skills and gain work experience.

To my esteemed supervisor, Dr John Mielke, you have been consistent with your support. In times of worry and self-doubt, you have provided calmness and reassurance. I have learnt so much from you, from your approach and passion for research rigour and quality to the genuineness and fervour with which you mentor and guide students. Thank you for providing reasonable deadlines and quick turnarounds with edits/suggestions while ensuring I maintained a healthy work-life balance.

I also wish to acknowledge the contribution of the following research assistants who contributed their time and effort to data collection: Claire O'Connor, Dana Ghanem, Yue Lai-Zhao, Osama Zitoun, and Tara Behroozian. Further, I would like to thank Clair O'Connor and

Osama Zitoun for contributing to the study search process for the project on hair cortisol measurement.

I would also like to express gratitude to the Waterloo Fire Rescue members who participated in our study, without which this project would be impossible. In particular, I would like to especially thank Brett Gibson, Luke Pedersen, Ryan Schubert, and the Leadership of the WFR for their enthusiasm and dedication to the success of this project. Also, I would like to express my gratitude to the Government of Alberta and the OHS Futures – Research Funding Programme for their generous financial support.

Thank you for making this journey worthwhile to all my friends, Ochai Okpe, fellow coursemates and laboratory mates. Thanks to the School of Public Health Systems and its excellent staff members: Brian Mills, Dan Rodgers, Carol Westbrook, and Michelle Fluit, I appreciate the support, employment, and excellent training throughout this journey. I also thank Mike Belfry for providing mentorship and engaging in political discourse during my time at AccessAbility Services.

My family, dad, mum, Obi, and Chim, you have been my bedrock of support throughout this journey. You have showered me with love, prayers, kind words of encouragement, and financial support from start to end. You were there in highs and lows, and I am grateful to have you all on my side. I also want to thank Mrs Bimpe Bamikole for all your support during my intensive writing period; all the delicious delicacies and words of encouragement were helpful.

Finally, I want to give special thanks to my fiancée, Solape Bamikole. You have been my rock and support system through the most crucial part of the journey. You kept me focused and constantly provided words of affirmation and upliftment. Thank you for your supportive listening and helping me maintain a healthy work-life balance.

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Chapter 1
INTRODUCTION

1.1 Overview

Over the past century, the global burden of chronic disease has rapidly increased and has overtaken infectious diseases as the leading cause of morbidity and mortality worldwide (Yach et al., 2004). For example, the Public Health Agency of Canada (2017) estimates that one in five adults in Canada suffers from at least one of the following chronic diseases: cardiovascular disease, cancer, diabetes, or chronic respiratory disorder. Specifically, within Ontario, the number of individuals living with a chronic disease rose significantly by 11% between the years 2008 to 2018 (Ma et al., 2021). Sadly, these figures are estimated to rise due to an increasing number of Canadians over 65 (PHAC, 2017). Coupled with the staggering morbidity and mortality rates associated with chronic diseases, they have negative economic and healthcare implications, significantly impacting society (Raghupathi & Raghupathi, 2018).

The rising prevalence of chronic diseases has raised concern amongst medical, research, and public health communities. Further, as the "epidemiological transition theory" clearly illustrates, we have moved beyond the era of infectious disease to that of chronic disease prevalence (Caldwell, 2001; Omran, 1971). The growing concern has led to extensive research into chronic disease causative factors and biomechanism. Contemporary research shows that the aetiology of chronic diseases is complex and multifactorial, with the interplay of modifiable (e.g., socioeconomic status) and non-modifiable (e.g., age) factors.

Despite the complex pathogenesis surrounding chronic diseases, one contributory factor, chronic stress, has stood out consistently, as overwhelming evidence supports its association with chronic disease development (Chandola et al., 2006; M. R. Salleh, 2008; Vanitallie, 2002). Chronic exposure to stress impacts biological resiliency and may weaken it, thus limiting the optimal functioning of homeostatic systems and predisposing individuals to various undesirable mental and physical conditions (Chandola et al., 2006).

Recent changes to social and cultural norms coupled with growing globalization have contributed to society's significant and rapid transformation and created novel challenges, such as the prevalence of psychosocial stress (Liu et al., 2017). Psychosocial stress, a common cause of chronic stress, is a frequently investigated kind of stress that consists of work-related stress, major life events, day-to-day hassles, and chronic strains (Oei et al., 2017).

Work-related psychosocial stressors have attracted growing attention because individuals spend considerable time on work activities and workplaces. Also, the growing prevalence of stress-related disorders ranging from burnout to more prolonged ailments and the accompanying economic and healthcare cost to individuals, organizations, and society has raised genuine concern about psychosocial workplace stress (Hassard et al., 2014).

Certain groups may experience psychosocial stress at far greater levels and bear the consequences of these stressors on their health. Of these groups, first responders, especially firefighters, have been shown by multiple studies to experience stress at high levels (Jacobsson et al., 2016; Rajabi et al., 2020). In addition, some psychosocial stressors affect firefighters' jobs and wellbeing; they include shift work, excessive workload, interpersonal/organizational conflict, and job insecurity (Beaton et al., 1998; Fisher & Etches, 2003). Further, the deleterious effect of these psychosocial stressors on firefighter health has been extensively studied, with manifestations including burnout (Smith et al., 2019), elevated blood pressure (Bongkyoo Choi, Schnall, et al., 2016), musculoskeletal disorders (Damrongsak et al., 2017), and sleep disorders (Yook, 2019).

The current body of research has established associations between psychosocial stressors and adverse health outcomes among firefighters. However, a crucial part of the underlying mechanism that captures the breadth and complexity of these stressors and how they become biologically embedded in such a manner to create physiologic and behavioural changes leading to chronic diseases within this group demands inquiry. Therefore, McEwen and Stellar's (1993) "allostatic load model" was adopted to provide a possible explanation for the cumulative biological impact of chronic exposure to psychosocial stressors on the health and wellbeing of firefighters.

In a nutshell, allostatic load (AL) represents physiological "wear and tear" occurring across all system levels (i.e., from the cellular to the organ level) from repeated exposure to stressful experiences. When multiple interconnected mediators of adaptation overcompensate and fail due to chronic activation of allostasis from stress exposure, AL rises (Korte et al., 2005; McEwen, 1998). Based on this, the AL model suggests that by evaluating the multi-system interactions among primary mediators (e.g., cortisol) and their effects, in synchrony with related secondary mediators (e.g., lipid profile) and outcomes (e.g., elevated blood pressure), a unique opportunity abounds to predict/identify individuals vulnerable to adverse tertiary outcomes such as cardiovascular diseases (Juster et al., 2010). Hence, investigating the association between the psychosocial stress experience and AL of firefighters is essential to address and prevent the rising risk of chronic disease in this group.

1.2 Study Rationale

To date, stress-related research within firefighting primarily reflects investigations into the nature of physical and traumatic stressors prevalent amongst firefighters and adverse health outcomes such as occupational and traumatic injuries (for example, post-traumatic stress disorder [PTSD], cardiovascular diseases, respiratory insults, and cancers) linked to these innate stressors (Fisher & Etches, 2003; Jahnke et al., 2012; Mustajbegovic et al., 2001). Despite the wealth of knowledge on physical and traumatic stressors and their outcomes, research effort and inquiry into another potent stressor, psychosocial stress, still lags. In the face of growing awareness of the threats psychosocial stress poses to the health and wellbeing of firefighters and the cost to public safety, there remains a lack of synthesized information detailing the prevalent psychosocial stressors unique to this occupational group and the health consequences accompanying them.

A growing body of evidence suggests that individuals who experience a high level of psychosocial stress are at significant risk for high AL and, subsequently, the development of chronic health conditions (Beckie, 2012; Marón et al., 2019). Similarly, there is good evidence to suggest that work-related psychosocial stress significantly elevates AL and subsequently elevates the risk of chronic disease development in different working-class adult populations (Bellingrath et al., 2009; Mauss et al., 2016; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003; W. Sun et al., 2011). Nevertheless, there has been no effort to apply the AL model in investigating the relationship between psychosocial stressors affecting firefighters and their health outcomes. Thus, there is immense value and an urgent need to investigate the mechanistic neurobiological pathway between work-related psychosocial stress and adverse health outcomes experienced by firefighters

Furthermore, regardless of the type of stressor prevalent within a professional group, certain factors, including demographic, behavioural, and personal psychosocial resources, may either potentiate, or attenuate its impact, especially on AL. For example, the availability of psychosocial resources like social support has been shown to either directly, or indirectly buffer the adverse health impact of psychosocial stress in the general population (Taylor et al., 2008; Taylor & Seeman, 1999). Likewise, the availability of psychosocial resources may affect AL progression (Wiley et al., 2017). Consequently, there has been an appreciable degree of inquiry into the influence of demographic, behavioural, and psychosocial resources on the psychosocial stress experienced by firefighters (Beaton et al., 1997; Murphy et al., 2002; Regehr, 2009; Soteriades et al., 2019, 2022). However, there has been a lack of investigation into the potential confounding, or modifying role these factors play in the psychosocial stress and AL relationship among firefighters.

The expanding application of the AL model in stress research underscores the utility of applying such a framework among firefighters. Therefore, my research will address a clear knowledge gap by answering the following primary research question, *"Does the psychosocial stress encountered by firefighters affect their allostatic load?"*

1.3 Objectives

The overarching aim of this dissertation will be to investigate the nature and types of psychosocial stress affecting a sample of firefighters and to apply perspectives from the allostasis and AL model to arrive at a contextual and in-depth understanding of how such stressors affect their health. Using investigative methods, I measured appraisal of perceived general-life and work-related stress and collected an index of physiological biomarkers representing AL to explore the relationship between psychosocial stress and AL in a group of active firefighters. **Figure 1** describes the investigatory focus within the AL model.

Further, other investigations were considered to accurately determine the association between psychosocial stress and AL in firefighters. First, the AL model was proposed as an empirical framework to investigate the underlying link between psychosocial stress and adverse health outcomes in firefighters. The proposed framework considered potential factors that may impact the psychosocial stress and AL relationship based on empirical findings from the general and working populations and stress-related studies on firefighters. This objective was addressed in chapter 3.

An essential aspect of the AL model is the compilation of biomarkers making up an allostatic load index (ALI) and its computation to reflect the AL in the investigated population. The choice to use specific biomarkers and collection feasibility were considered and described in the Methods section (section 4.3.4). Different scoring methods are available for ALI computation, with the group-count method (the risk-quartile and clinical-norm types) frequently applied (D'Amico et al., 2020; Juster et al., 2010; Seeman et al., 1997). For this study, the method used for scoring the ALI was the risk-quartile group-count method based on supporting evidence provided in the Methods section (section 4.3.4).

The choice not to use the clinical (norm) count-based method was based on a limitation experienced with this technique: the lack of standardized cut-offs for frequently used biomarkers (D'Amico et al., 2020). For example, among the physiological biomarkers used to determine the ALI within our sample, hair cortisol concentration (HCC) still lacks an established normative threshold value. Although there is a growing appreciation for HCC assessment across stress and AL research, there remains a need to address the lack of an HCC threshold value found in healthy adults. In addition to the need to provide a normative HCC value that would be useful for ALI scoring based on clinical (norm) cut-offs, there is an eager desire to provide such an HCC value for future investigations in public health and clinical research. This research gap prompted efforts to meet this objective in study 2 (chapter 4).

Identifying and consolidating work-related psychosocial stressors and their related health outcomes investigated across studies is essential to understand better how prevalent these stressors are and to allow us to document their potential impact on the health and wellbeing of firefighters. In addition, identifying these stressors will help explain the prevalent work-related psychosocial stressors present within our investigated group and provide context for the results from studies 4 and 5 (i.e., chapters seven and eight, respectively). Further, although my research's primary focus is on the relationship between psychosocial stressors and AL (Figure 1), identifying the adverse health outcomes commonly associated with such stressors will provide a clearer picture of the entire stress-AL-outcome cascade within firefighters. Hence, this objective was addressed in study 3 (chapter six).

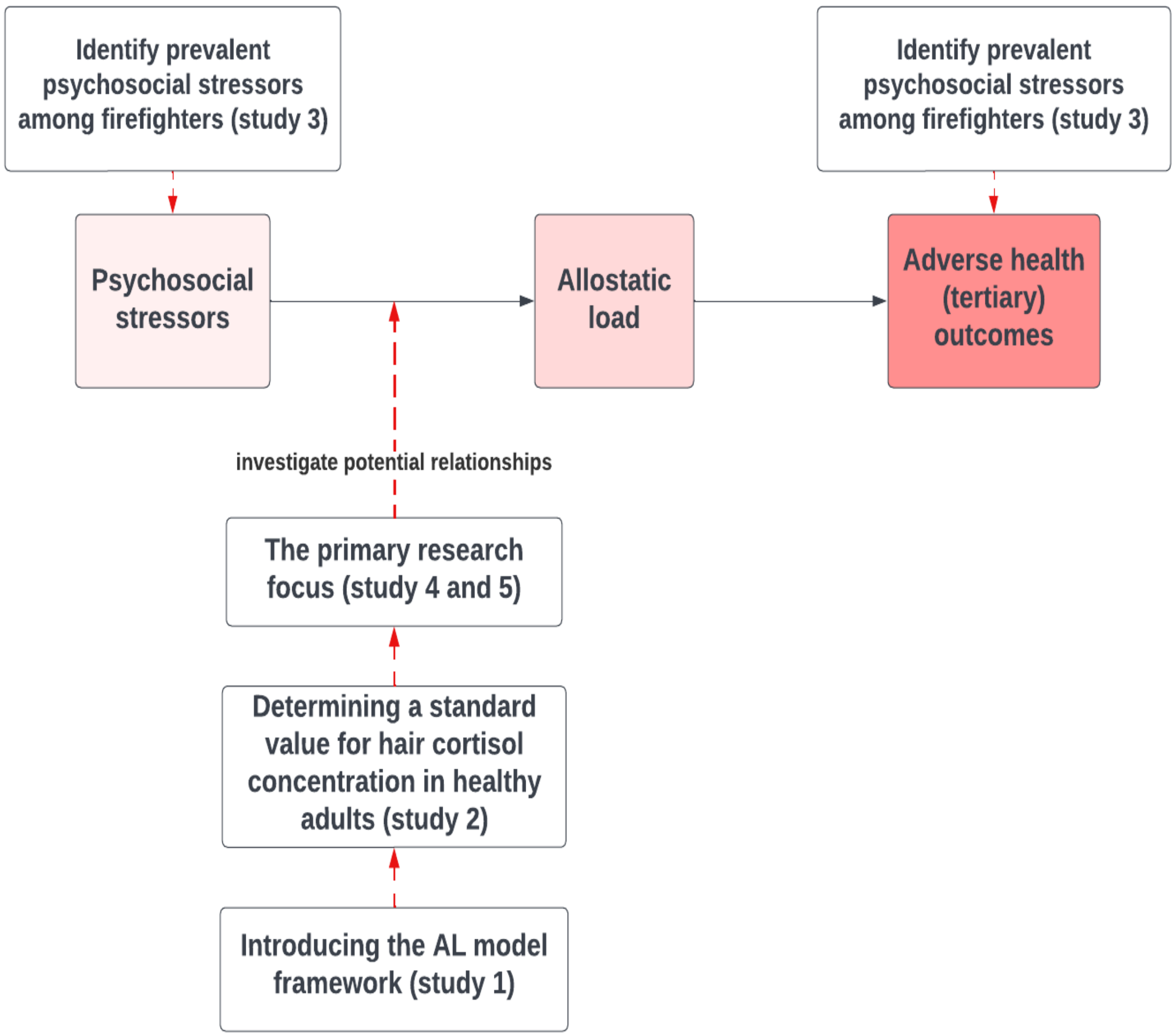

Figure 1. Diagram illustrating the focus and objectives of the studies forming the present thesis

1.3.1 Specific objectives

Study 1: An introductory study that puts forward the AL model as a framework to explore the cascade of processes that begin with chronic exposure to work-related psychosocial stress and lead to the development of adverse health outcomes, including chronic diseases among firefighters.

Objective 1: To put forward an argument for the operationalization of the AL model to investigate the impact of psychosocial stress on the health and wellbeing of firefighters.

Objective 2: To highlight potential challenges and opportunities the AL model provides when applied within stress research targeting firefighters.

Study 2: A systematic review and meta-analysis of the literature on scalp hair cortisol concentration (HCC) to determine a standard value of HCC in healthy adults.

Objective 1: To synthesize literature on HCC with a primary focus on immunoassay methods.

Objective 2: To put forward a recommended clinical threshold value of scalp HCC in healthy adults.

Study 3: A systematic review of the literature to explore work-related psychosocial stressors affecting firefighters and their associated health outcomes.

Objective 1: To investigate the types of work-related psychosocial stressors prevalent amongst firefighters.

Objective 2: To determine which health outcomes are associated with work-related psychosocial stress experienced by firefighters.

Objective 3: To highlight the prevalent psychosocial resources among firefighters and their effects on health and wellbeing.

Study 4: A cross-sectional study designed to investigate the relationship between work-related psychosocial stress and AL and explore the moderating role of social support within a sample of Canadian firefighters.

Objective 1: To investigate the relationship between work-related psychosocial stress experienced by firefighters and their AL.

Objective 2: To explore the impact of demographic characteristics such as age and length of service and behavioural habits (e.g., alcohol consumption) on perceived stress level and AL.

Objective 3: To determine if social support moderates the effect of psychosocial stress on AL amongst a sample of firefighters.

Study 5: A longitudinal study investigating firefighters' AL over one year.

Objective 1: To determine if perceived psychosocial stress at baseline predicted change in AL over time.

Objective 2: To understand what role age and social support played in the stress and AL relationship.

Objective 3: To investigate the prevalence of Covid-related stress among the sample of firefighters and ascertain its impact on the PS-AL relationship.

1.4 Thesis structure

As with most article-based thesis, certain content will be repeated; you may find segments of the literature review and methods included in similar sections (introduction and methods) in the subsequent chapters.

This thesis is organised into nine chapters (**Figure 2**). Chapter one provides a critical overview, rationale, and objectives of the thesis. The second chapter provides a theoretical background and literature review on stress (particularly psychosocial stress) and its biological embedding with a specific interest in the working population. In addition, a brief description of firefighters is provided, including their working environment details. Chapter three represents study 1, which details the primary stressors inherent to firefighting and a proposed framework for applying the AL model as a novel approach to investigating work-related psychosocial stress impact on firefighter health. Chapter four provides a general overview of the methods used in all studies included in the thesis. Chapter five contains study 2, representing the systematic review and meta-analysis to determine the clinical threshold value of scalp hair cortisol concentration in healthy adults using immunoassay methods.

Chapter six contains study 3, representing the systematic review highlighting work-related psychosocial stressors, their health impact, and resources that may buffer the impact of stress among firefighters. Chapters seven and eight, which represent studies 4 (cross-sectional analysis) and 5 (longitudinal analysis), investigate the association between perceived psychosocial stress and the AL in a sample of Canadian firefighters. Finally, chapter nine provides an integrated discussion connecting critical findings from the individual studies and their contributions to stress research.

For coherence and avoidance of repetition, references from individual studies are listed at the end of the thesis.

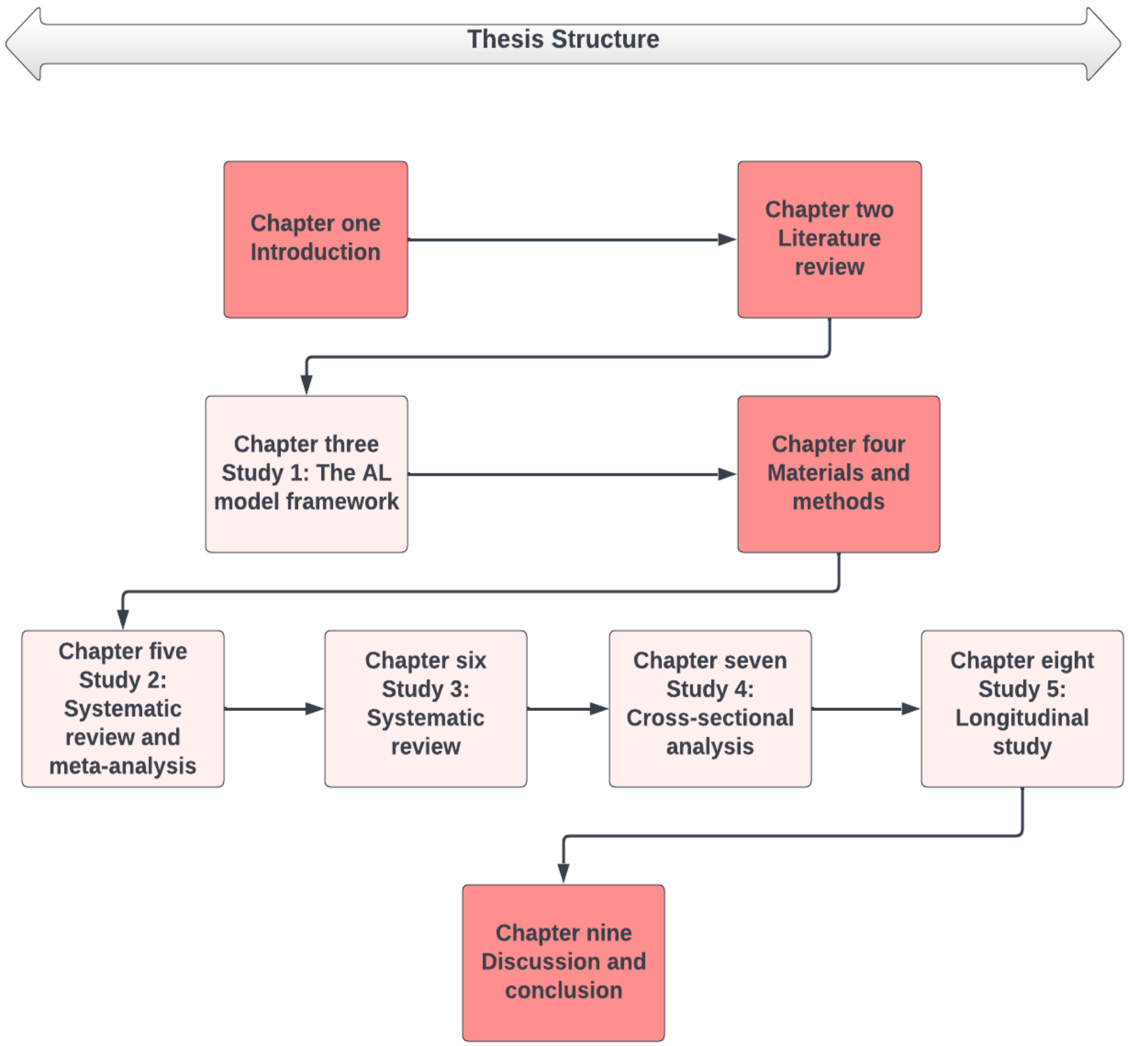

Figure 2. Diagram illustrating the thesis structure.

Chapter 2

LITERATURE REVIEW

2.1 Stress

Questions regarding the dangers of stress have been asked for decades, with the generally assumed notion that all types of stress, regardless of the stressor, are detrimental to health. Research into stress pathophysiology has improved our understanding of the types of stress and the different stress responses they elicit. The current evidence shows that transient stress responses are essential for survival; however, as observed in chronic stress, its prolongation can negatively affect the body's functioning (McEwen, 2000). Thus, to fully grasp the stress concept and its manifestation, the critical aspects of its dynamic process need to be elucidated. The critical aspects include the nature and severity of a stressor, the elicited response, its mediators, and how it may alter the physiological functioning of the human body systems.

2.1.1 What is stress?

The word "stress" may invoke different meanings based on its use context. Often, it is described as an unpleasant stimulus that elicits a response that is typically harmful to the recipient. Further, different authors have provided their interpretations of stress. One of the earliest definitions of stress comes from an author whom many consider the pioneer of stress research, Hans Selye, M.D. Selye's widely respected seminal work, "The Stress of Life", defined stress as "A non-specific response of the body to a demand" (Selye, 1956). In addition, other definitions are contextually situated in the stressor and stress response. For example, stress is a series of events that start from the reception of a stimulus or stressor, which triggers a cognitive brain reaction, or stress perception, thereby activating the physiological fight-or-flight systems in the body as a stress response (Dhabhar & McEwen, 1997). McEwen (2002) further describes stressors as those that "elicit a hormonal or behavioural response even if physiological homeostasis is not compromised" (McEwen, 2002).

Another definition of stress experience classifies it into good, tolerable, or toxic stress (Shonkoff et al., 2009). Good stress or eustress represents the exhilarating feeling of risk-taking, meeting a challenge, and receiving a positive outcome. Major components of this type of stress are healthy self-esteem, firm impulse control, and decision-making capability (McEwen, 2016). Hence, this positive type of stress emphasizes adaptability as it strengthens the body's adaptation systems and serves as a biological warning system (M. R. Salleh, 2008). Tolerable stress appears in events with negative experiences; however, the individual is equipped with coping resources and support to overcome the situation (McEwen, 2016; Shonkoff et al., 2009). In addition, the tolerable stress experience prepares and conditions the individual against future threats. Finally, toxic stress appears when the individual lacks the brain capacity from early adverse life experiences that may impact internal and external resources like social support, impulse control, and self-esteem, which are necessary to deal with negative experiences. The low tolerance to toxic stress may result in adverse behavioural and physiological consequences (McEwen, 2016; M. R. Salleh, 2008).

Clark et al. (2007) described yet another framework to describe stress using environmental, psychological, and biological approaches. First, the environmental approach describes stress as change, which emanates from an assessment of one's experience or environmental situation. Such change is measured by the frequency and severity of significant events requiring adaptive responses over a specific period (Clark et al., 2007). Second, the psychological approach emphasizes the subjective perception and evaluation of one's life events. Hence, it differentiates between primary appraisal of a stressor as harmless or threatening and secondary appraisal of resources when a coping response is needed (Clark et al., 2007). Finally, the biological approach describes stress as the activation of physiological response systems, including the hypothalamic-pituitary-adrenocortical (HPA) axis, the sympathetic-adrenal medullary (SAM), and the immune system (Clark et al., 2007; M. R. Salleh, 2008). With reference to these approaches, stress may be defined as the process wherein environmental demands disrupt one's perception of stress and, subsequently, their adaptive capacity, thus increasing the risk of disease.

A meta-analysis by Kogler et al. (2015) differentiates stress based on neural engagement into physiological and psychosocial stress. Physiological stress is described as odious sensory, emotional, and subjective experiences linked to physical and homeostatic systems threats, with possible body tissue damage. Examples include pain, dehydration, malnutrition, and oxidative stress (Kogler et al., 2015). On the other hand, psychosocial stress is provoked by social threats, including social exclusion and evaluation. For example, individuals desire social awareness and inclusion; social threats to this need may induce stress. Similarly, stress may arise from social evaluation because of the unpredictability of certain interactions or outcomes (Kogler et al., 2015). Hence, Kogler and colleagues summarised that physiological stressors elicit a motoric flight-or-fight response, while psychosocial stressors shift one's attention to cognitive regulation of emotion while downregulating reward processing (Kogler et al., 2015).

Irrespective of the stressor, duration and periodicity also influence stress response. Acute stress is transient and lasts for minutes to hours, while chronic stress lasts for several hours during the day and endures for several weeks or months (Dhabhar & McEwen, 1997). Authors have used various time thresholds to differentiate acute from chronic stress, but the most commonly used threshold is stress lasting at least for 6-months representing chronic stress (Hammen et al., 2009; Mazure, 1998). The acute and chronic stress classification is fundamental in the different neurobiological stress responses and consequences they elicit (Hammen et al., 2009).

2.2 The adaptive stress response

In the face of intrinsic or extrinsic stressors, the body responds physiologically by activating the two main central control stations (HPA and SAM axes) for the effector pathways in the hypothalamus and the brain stem. Furthermore, a behavioural component of the stress response exists; for example, compensatory behaviour involving conscious control includes comfort eating, exercise, alcohol intake, tobacco use, and recreational drug consumption (Chrousos & Gold, 1992; McEwen, 2000c).

2.2.1 Stress response and the HPA axis

In the event of a threatening stimulus, regardless of its nature, the HPA axis is quickly activated to produce glucocorticoids. Certain areas in the brain (initial response) stimulate the hypothalamus in coordination; afferents from the limbic system, which integrate cognitive and emotional control combine with visceral, somatosensory, auditory, nociceptive, and visual input to the hypothalamus, act on the paraventricular nucleus (PVN), which synthesizes corticotropin-releasing hormone (CRH) (Turnbull & Rivier, 1999). CRH travels via a portal from the hypothalamus to the anterior pituitary, where it signals the corticotrophs to produce the peptide proopiomelanocortin (POMC) and, subsequently, the secretion of adrenocorticotropin hormone (ACTH; Turnbull & Rivier, 1999). ACTH then travels via systemic circulation to the zona fasciculata of the adrenal cortex and stimulates the production of glucocorticoids, of which cortisol is the primary messenger in humans (**Figure 3**). Subsequently, elevated glucocorticoid levels initiate negative feedback that suppresses the production and secretion of CRF within the hypothalamus and POMC-derived peptides, including ACTH; this action suppresses glucocorticoid levels as part of its adaptive stress response (Godoy et al., 2018; Juster, Russell, et al., 2016; Turnbull & Rivier, 1999).

Glucocorticoids are active compounds that serve essential functions in the adaptive stress response. First, glucocorticoids exert their actions via their widespread receptors, glucocorticoid receptors, to control the basal activity of the HPA axis, which is vital in regulating and halting a stress response appropriately. These hormones act on the PVN, anterior pituitary, and other higher centers like the hippocampus to regulate the HPA axis (Godoy et al., 2018; Kyrou & Tsigos, 2009). Secondly, cortisol, acting via its glucocorticoid and mineralocorticoid receptors, activates the glucocorticoid responsive elements (GRE) that upregulate or suppress various genes involved in metabolic, immune, and cognitive processes and other critical processes physiological functions (Kyrou & Tsigos, 2009). Broadly, cortisol amplifies genes responsible for energy creation (e.g., glycolysis) and distribution, lipoprotein metabolism and lipolysis, and amino acid breakdown (Kyrou & Tsigos, 2009). Cortisol also downregulates the following genes: CRH (via negative feedback); interleukin–- 6 & 8, tumor necrosis factor-alpha (TNF-α) responsible for pro-inflammatory response; prolactin (suppresses reproduction); proopiomelanocortin (suppresses appetite); and adiponectin resulting in atherogenesis and insulin signalling (Kyrou & Tsigos, 2009).

2.2.2 Stress response and the SAM axis

The SAM axis responds quickly to threatening stimuli and involves an immediate physiological response mediated by catecholamines: epinephrine and norepinephrine (Godoy et al., 2018; McCorry, 2007). The locus-coeruleus (LC) plays a vital role in this adaptive stress response. The LC, a pontine nucleus adjacent to the fourth ventricle, holds the majority of norepinephrine-expressing neurons in the brain that supply the whole neuroaxis and work in tandem with the PVN during stress response (Godoy et al., 2018). Most sympathetic postganglionic fibres originating from LC release norepinephrine after receiving stimuli from the limbic system. The pre-ganglionic fibres from LC that do not connect with sympathetic postganglionic neurons directly synapse with the adrenal medulla chromaffin cells (**Figure 3**). Thus, the adrenal medulla is responsible for the synthesis and secretion of epinephrine (80% of secretion) and norepinephrine (20% of secretion).

Catecholamines interact with adrenergic receptors on smooth muscle cell membranes in numerous organs and on several neurons across the central nervous system (CNS). The adrenergic receptors are G-protein coupled receptors (responsible for effector protein regulation) nested in the cell membrane (Godoy et al., 2018; McCorry, 2007). The stress response involving the catecholamines and the SAM axis leads to general physiological changes that ready the body for a "fight-or-flight" reaction. It encompasses all activities that maintain alertness, cardiovascular actions, and metabolic activities, including elevated glucose levels (glycogenolysis and gluconeogenesis) and lipolysis (Godoy et al., 2018).

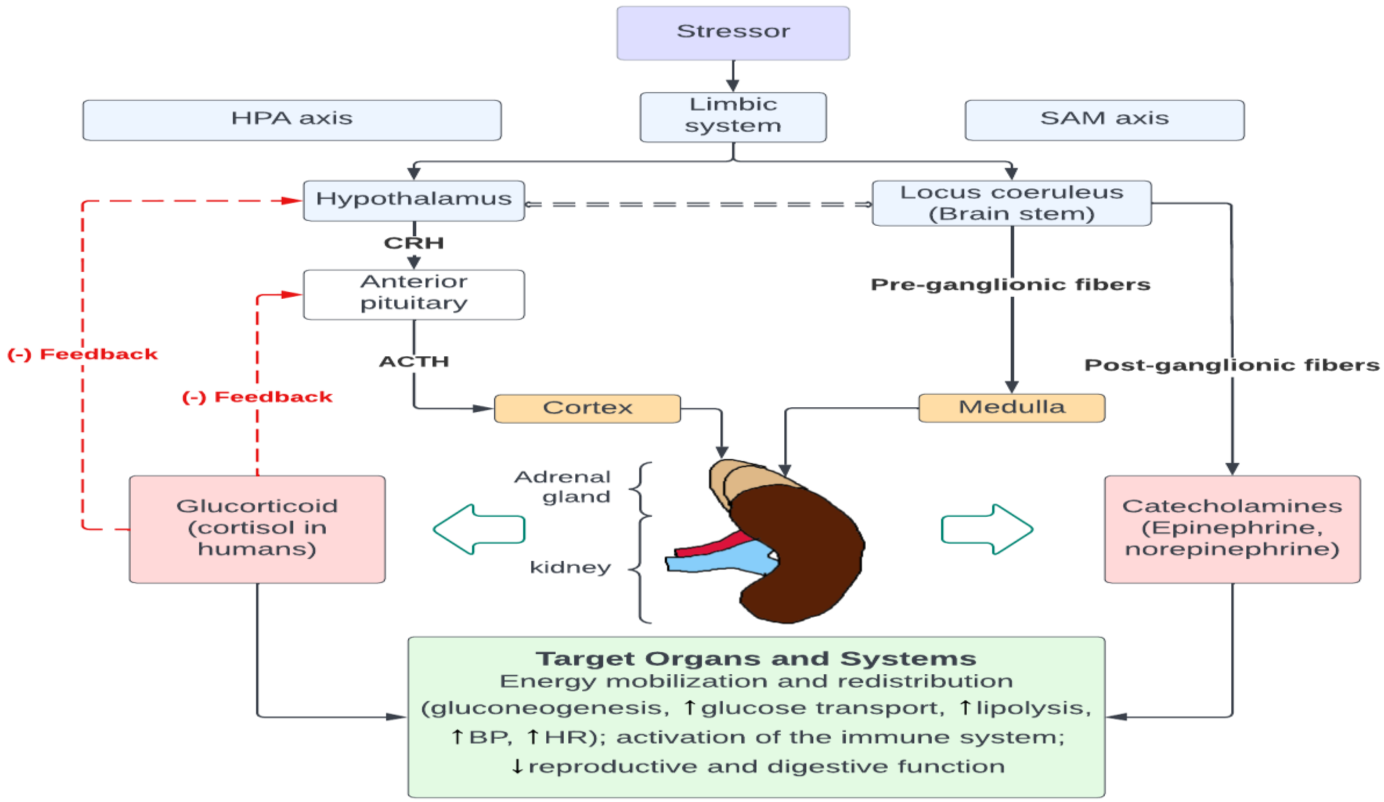

Figure 3. The adaptive stress response. ACTH, adrenocorticotropin hormone; BP, blood pressure; CRH, corticotropin-releasing hormone; HR, heart rate

2.2.3 Stress response and the immune system

Immune system activation is vital to prepare and protect the body against pathogens and physical injury. The immune system is activated based on the stressor's magnitude, duration, and frequency and can be stimulated by both the HPA and SAM axes (Godoy et al., 2018). In addition, primary mediators such as glucocorticoids and catecholamines facilitate a systemic transition from cellular (Th1) immunity to humoral (Th2) immunity, thereby controlling the activity of leukocytes and accessory immune cells (Chrousos, 2009). This process involves the redistribution of leukocytes, immunoglobulin production, and selective cytolytic activity (Chrousos, 2009; Pruett, 2003).

Further, several cytokines, especially the pro-inflammatory kind, including Interleukin-1(IL-1), TNF-α, and Interleukin-6, can activate the HPA axis in response to stress (Glaser & Kiecolt-glaser, 2005; Pruett, 2003). For example, CRH production by the hypothalamus is influenced by IL-1; hence, the cytokine-mediated elevation of CRH stimulates glucocorticoid production that suppresses further inflammatory action of cytokines. This action constitutes an essential negative feedback loop that keeps the inflammatory response in check, protecting the organism (Chrousos, 2009; Glaser & Kiecolt-glaser, 2005).

2.3 Homeostasis model

The Homeostasis model was the central framework to elucidate the stress response mechanism. McEwen and Wingfield (2003) define homeostasis as the “stability of physiological systems that maintain life.” The concept of homeostasis was premised on the need to maintain optimal set points of essential systems via a consistent self-correcting feedback system; the essential systems include the PH, body temperature, glucose level, oxygen tension, and osmolarity (McEwen & Wingfield, 2003; Sterling & Eyer, 1988).

Vital attributes of the homeostatic model include a coordinated physiological response (consists of 'homeostats' and multiple effectors) and a regulatory feedback mechanism to re-establish the internal milieu (static setpoints) after disruption of one or more essential systems (Cicchetti, 2011; McEwen, 2002). Homeostats (sensors) are central to the homeostatic model as they compare discrepancies from the setpoints established by regulators to provide an adequate response during perturbations. Further, in tandem with the feedback mechanism, the effectors exert the necessary change in values on the controlled variable to maintain homeostasis (Goldstein & McEwen, 2002).

Although homeostatic systems automatically correct deviations from standard setpoints, it fails to account for the daily variations needed for a broad range of compensatory and anticipatory responses to environmental demands (Ganster & Rosen, 2013). In contrast, these demands require a dynamic adaptive response that considers the need for progressive adjustments (reconfiguring the setpoints) of the internal physiological environment to meet challenges (Seeman et al., 1997). In addition, an adaptive stress response provides energy mobilization and redistribution necessary to maintain homeostasis; this action happens at the cost of recalibrating many biological functions (Kyrou & Tsigos, 2009). Hence, these adaptive processes are essential to actively maintaining homeostasis (McEwen, 2002).

2.4 The concept of allostasis

Sterling and Eyer (1988) introduced the concept of allostasis to explain the dynamic adaptive stress response. They defined allostasis as "stability through change." In detail, allostasis is the dynamic and multifaceted process regulated by the brain, where an organism preserves its physiological stability by recalibrating homeostatic parameters to adequately respond to environmental demands (Juster et al., 2010; Sterling & Eyer, 1988).

Although the allostasis model has been likened to homeostasis since they are closely related, they differ in capacity (**Figure 4**). Unlike homeostasis, the allostasis model acknowledges the brain's actions in feedback regulation, focuses on dynamic instead of static biological setpoints and considers health as a complete body adaptation to change based on contextual needs (Juster et al., 2010; Schulkin, 2003). Hence, under allostasis, the brain (hippocampal, prefrontal cortex, and amygdala) actively evaluates threats or physiological needs and readily adapts to these demands with greater flexibility and anticipation, using prior experience and knowledge (Ganster & Rosen, 2013). Threat perception and the deployment of allostatic systems depend on differences in individual constitutional (genetics, development), behavioural (coping), and historical (adverse life events, trauma, abuse) factors (McEwen, 1998).

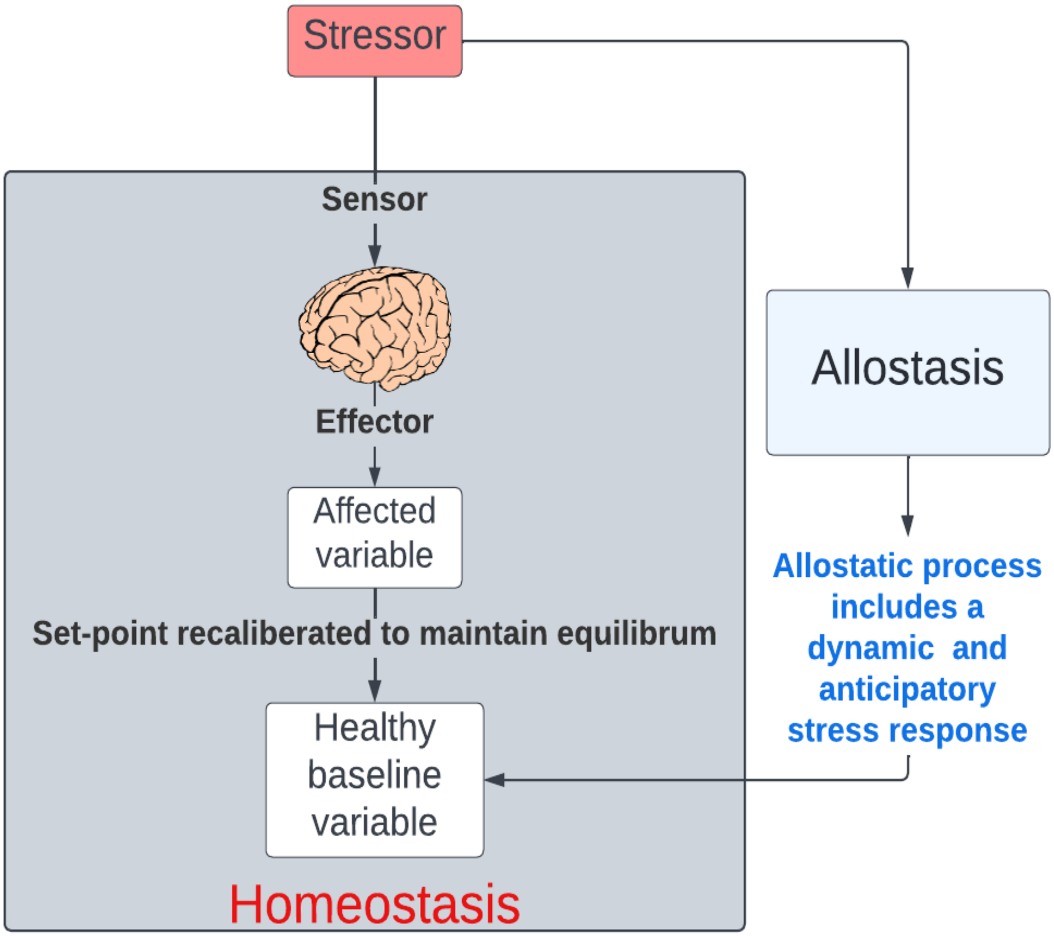

Figure 4. Homeostasis and its connection to allostasis in response to a stressor

Allostatic responses to demands include changes across a range of operating systems (e.g., HPA axis) to either intensify or down-regulate vital functions to achieve a new steady state of functioning (Ganster & Rosen, 2013). For example, Sterling and Eyer (1988) describe allostasis in action using variations in blood pressure, where an increase in blood pressure occurs on getting up from the bed in the morning to maintain the oxygen tension in the brain. In another example, the release of allostatic effectors, catecholamine and cortisol during physical activity gather and replenish energy sources required by the brain and body under challenge, thus, maintaining optimal body temperature and essential metabolism (McEwen, 2002).

Like every functional system, the allostatic system undergoes progressive "wear and tear" due to repeated use. The strain put on the body by the chronic challenging stimuli (e.g., psychosocial situations) and the strain arising from repeated activation of allostatic effectors can lead to significant changes (primary effects) in cellular activity. Over time, these cumulative changes may adversely disrupt the integrity of physiological systems and ultimately produce disease (Korte et al., 2005; Seeman et al., 1997).

2.5 The allostatic load theory

The AL theory provides a comprehensive account of the physiological mechanism underlying exposure to various stressors experienced throughout life, culminating in adverse health outcomes (Simandan, 2010). While adaptive in the short term, repeated allostasis to environmental demands creates a cumulative physiological cost to interconnected biological systems, which overcompensate and eventually collapse. Furthermore, such maladaptation may produce systemic vulnerability to stress-related outcomes (Juster et al., 2010). Hence, AL may be defined as the cumulative strain and energy cost from repeated activation of allostasis that results in wear and tear occurring at the cell, tissue, and systemic and supra-cellular levels within the human body (Juster, Russell, et al., 2016; Korte et al., 2005; Seeman et al., 1997).

2.5.1 Allostatic states

The development of allostatic states results from a disruption of the allostatic systems and loss of cognitive appraisal and response to stressors because of brain changes from chronic stress (e.g., repressed neurogenesis, dendritic remodelling; McEwen, 2000). These pathophysiological allostatic states represent different response patterns that lead to sequential dysregulation of multiple systemic mediators; they include the *repeatedly activated response* state, the *non-habituating response* state, the *prolonged response* state, and the *inadequate response* state (Juster et al., 2010; McEwen, 1998). The repeatedly activated response state describes the uncontrollable and frequent exposure to multiple novel stressors resulting in progressive elevation of allostatic mediators over an extended period. This state may progress into other states as the body either fails to respond adequately to stimuli or fails to regulate an ongoing response. The second state, the non-habituating response, describes a failed adaptation to the same stressor leading to the continuous activity of stress mediators. The prolonged response state represents a failure to end the hormonal stress response or to maintain a regular circadian pattern (McEwen, 2002). Finally, the inadequate response is a state of hypoactivity due to compensatory hyperactivity of other allostatic mediators; for example, insufficient cortisol secretion leads to higher levels of cytokines due to unavailable counter-regulation by cortisol (Juster, Russell, et al., 2016; McEwen, 2000b).

2.5.2 Allostatic load and system malfunction

McEwen and Seeman (1999) narrate the steps by which AL culminates in disease (**Figure 5**). Allostatic effectors or "primary mediators" (e.g., cortisol, epinephrine, norepinephrine, cytokines), primarily responsible for regulating cellular events, are activated in response to stress. The actions of these primary messengers are essential to adapt to demands that threaten homeostatic systems. The cumulative product of chronic activation of primary mediators and subsequent primary effects is reflected in the release of secondary mediators. Further, the release of secondary mediators is related to adjusting standard operating setpoints in different biological systems. Secondary mediators include factors within the cardiovascular (e.g., blood pressure), immune (e.g., fibrinogen), and metabolic (e.g., glucose, cholesterol) systems. When secondary mediators continuously fall outside their standard ranges (dysregulations), they become leading risk factors for mental and physical diseases (Ganster & Rosen, 2013). The secondary outcomes such as increased blood pressure and cholesterol levels may not exert permanent damage at this stage; however, the continuation of dysregulation of secondary mediators with time gives rise to the next stage, the tertiary phase. The tertiary phase reflects the disease endpoints stemming from the AL, e.g., cardiovascular disease, cognitive decline, and death (Ganster & Rosen, 2013).

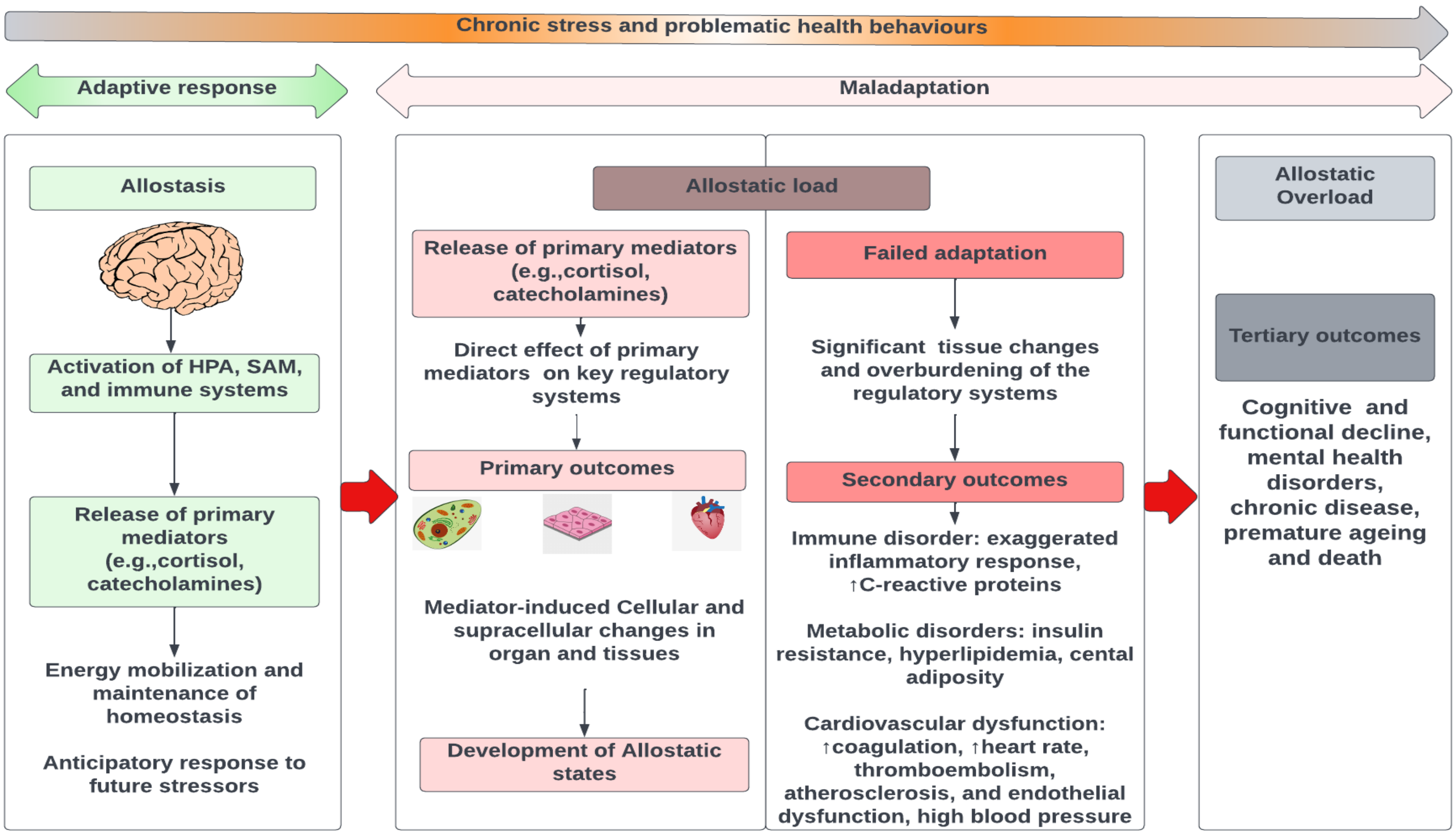

Figure 5. Allostasis, allostatic states, and Allostatic (over)load. HPA, hypothalamic-pituitary-adrenal; SAM, sympathetic-adreno-medullar

2.5.3 The Allostatic Load Index

Since the AL model introduction by McEwen and Stellar (1993), many empirical studies have utilized the AL model to investigate various antecedent stress factors (environmental and individual) and their possible relationships to produce adverse health outcomes. Seeman and colleagues were the pioneers in assessing AL by assembling various physiological biomarkers into an index measure (Seeman et al., 1997). Thus, the AL index (ALI) is a measure that summarizes the multi-systemic interplay among primary mediators and their effect in connection with related sub-clinical biomarkers representing secondary outcomes (Juster et al., 2010). A primary utility of the ALI lies in its capacity to identify or predict the risk of development of tertiary outcomes, that is, disease and mortality (Seeman et al., 1997).

One of the earliest works done to test the predictive capacity of the ALI was carried out by Seeman and colleagues; ALI was calculated as a composite score representing the weighted 'risk' levels of ten AL biomarkers (Seeman et al., 1997; **Table 1)**. The biomarkers used included the following primary mediators: serum dehydroepiandrosterone sulfate (DHEAS, a functional HPA axis antagonist), 12-hour urinary epinephrine and norepinephrine (integrated indices for 12-hour sympathetic nervous system activity), and 12-hour urinary cortisol (a measure of HPA axis activity). In addition, biomarkers for secondary outcomes included systolic and diastolic blood pressure (indices for cardiovascular activity), total cholesterol (TC) and high-density lipoprotein (HDL) (indices of long-term atherosclerotic risk), total glycosylated haemoglobin (a measure of glucose metabolism), and waist-to-hip ratio (an index for a long-term measure of metabolism and adipose tissue deposition).

Subsequent studies have adopted the original set of biomarkers (Clark et al., 2007; Seeman et al., 2001), but other combinations of biomarkers for the ALI have been considered (**Table 1**). For example, Gersten (2009) used a combination of biomarkers called the neuroendocrine allostatic load (NAL), comprising cortisol, norepinephrine, epinephrine, and DHEAS. Another combination was adopted by Evans et al. (2007); they combined six biomarkers, namely cortisol, epinephrine, norepinephrine, BMI, systolic blood pressure (SBP), and diastolic blood pressure (DBP), to calculate ALI. Recent studies by Mauss et al. (2015, 2016) suggest using the “big 5”, which includes DBP, glycosylated haemoglobin (HbA1c), low-density lipoprotein, waist circumference, and heart rate variability (HRV) biomarkers.

Despite the utility of different biomarkers spanning neuroendocrine, immune, and cardiovascular systems, an accepted gold standard for the exact biomarkers that an ALI should consist of does not exist, especially when considering contextual limitations of different studies (e.g., investigated population, availability of biomarkers measurement tools). However, the consensus is that ALI should contain at least one variable from the neurophysiological pathways (primary mediator) and a biomarker with significant predictive power for disease (secondary mediator) (Mauss, Jarczok, et al., 2015).

Study	**Stress mediation**	**System**		**Allostatic load biomarker**
Seeman et al. (1997)	Primary mediators	Neuroendocrine	HPA	12-hour urinary cortisol
				Serum dehydroepiandrosterone sulfate
			(SAM)	12-hour urinary epinephrine
				12-hour norepinephrine
	Secondary mediators	Metabolic		Waist-to-hip ratio
				Total cholesterol
				Serum high-density lipoprotein
				Glycosylated haemoglobin
		Cardiovascular		Diastolic blood pressure
				Systolic blood pressure

Study	Stress mediation	System	Allostatic load biomarker
Mauss et al. (2015, 2016)	Primary mediators	Neuroendocrine	Heart rate variability
	Secondary mediators	Metabolic	Low-density lipoprotein
			Glycosylated haemoglobin
			Waist circumference
		Cardiovascular	Diastolic blood pressure

Table 1. The "original ten" biomarkers used in the MacArthur Study of Successful aging (Seeman et al., 1997) and the "big five" biomarkers used in the Mannheim Industrial Cohort Studies (Mauss et al., 2015, 2016). HPA, Hypothalamic-pituitary-adrenal; SAM, Sympathetic-adreno-medullar

Further, to calculate the ALI, values of the various biomarkers are transformed into a summary index score. Numerous scoring algorithmic formulations and techniques have been employed to compute the ALI, including the simple group-based method (classic risk quartiles or clinical thresholds), grade of membership, canonical correlation, z-score averaging, and recursive partitioning (Juster et al., 2010; **Table 2**). Other methods include the two-tailed $10^{th}/90^{th}$ percentile approach (Seplaki et al., 2005) and the clinical ALI formula for medical practitioners proposed by Bizik et al. (2013).

Although there is a lack of consensus on an agreed-upon ALI scoring system, the group-based method is the most frequently used, especially the risk-quartile technique (D'Amico et al., 2020; Mcloughlin et al., 2020). In the risk-quartile method, the number of biomarkers entering the high-risk percentile (i.e., the upper or lower 25^{th} percentile) stemming from the sample's distribution are summed up. Further, while the clinical threshold method shares the summation technique used in the risk-quartile method, it differs from this method by comparing each biomarker to the corresponding predefined clinical threshold value. In both count methods, biomarker values are dichotomized as 0 or 1 depending on values falling within the high-risk quartile or exceeding the clinical cut-off (assigned "1") or values falling below the risk quartile or clinical cut-off (normal range, scored "0"). Higher overall values indicate higher AL or increased physiological strain, while lower values represent better adaptability to stress (Seeman et al., 2001).

Irrespective of the approach used to assemble the ALI (e.g., choice of biomarkers, number of biomarkers measured) and the scoring method administered across studies, studies have mostly found similar associations between AL and adverse health outcomes (Seplaki et al., 2005). Current evidence shows that high AL increases the risk of cardiovascular disease (Gillespie et al., 2019; Karlamangla et al., 2002; Nelson et al., 2007), metabolic disorders like diabetes (Steptoe et al., 2014), musculoskeletal disorders (Goertzel et al., 2006; Mori et al., 2014), periodontal disease (Sabbah et al., 2018), and all-cause mortality (Karlamangla et al., 2002; Seeman et al., 1997, 2001).

Regarding cognitive and mental health, AL has been shown to elevate the risk of poor mental health outcomes, including depressive/anxiety disorders, psychosis, and cognitive decline (Guidi et al., 2021; Juster et al., 2010). For instance, cross-sectional and prospective studies have produced findings that support a significant link between elevated AL and depressive and anxiety disorders (Carbone, 2021; Juster et al., 2018; Juster, Marin, et al., 2011; Kobrosly et al., 2014). Similarly, high AL has been linked to a higher prevalence of psychotic symptoms, especially those linked to schizophrenia and bipolar disorders (M. Berger et al., 2018; Bizik et al., 2013; Piotrowski et al., 2019). Regarding cognitive functioning, a meta-analysis of 11 studies by D'Amico et al. (2020) found a cross-sectional association between high AL and impaired global cognition and executive functioning.

Formulation		Description
Group-count method	Risk-quartiles (classic)	- Summary measure representing the number of biomarkers falling within a high-risk percentile (i.e., upper or lower 25th percentile) based on the sample's distribution of biomarker values. - Because each biomarker is dichotomized as 0 or 1 depending on cut-offs, each biomarker is allotted an equal weight in the index.
	Clinical threshold	- Summary measure representing the number of biomarkers falling within a high-risk percentile (i.e., upper or lower 25th percentile) based on a population's distribution of normative biomarker values used in clinical practice.
z-Score ALI		- The summary measure represents the sum of an individual's obtained z-scores for each biomarker based on the sample's distribution of biomarker values. - This standardized formulation allows the weight of each biomarker to be different depending on its deviation from the sample's mean.
Difference allostatic load score		- Difference between two time-points for a single biomarker or an index measure of multiple biomarkers.
Dynamic allostatic load score		- Repeated measures analysis or change scores between three or more time points for single or multiple biomarkers.

Nominal allostatic load grouping	- Dividing participants into groups based on an ALI threshold (e.g., 23 or 34). - The threshold cut point can be based on previous studies with a similar number of biomarkers or arbitrarily based on the sample's distribution.
Bootstrapping	- The resampling technique makes inferences about population parameters by generating multiple repetitive computations that estimate the shape of a statistic's sampling distribution. - The obtained bootstrap statistic can be used as weights for allostatic load biomarkers and/or indices in subsequent analyses.
Canonical correlation	- The multiple correlational analysis measures the association between two sets of latent variables representing an independent set and a dependent set. - It has been used to determine the best linear combinations of weighted AL biomarkers at baseline that are maximally correlated to tertiary outcomes like mortality at follow-up.
Recursive partitioning	- The multivariate reduction technique generates categories to classify participants precisely based on several dichotomous dependent variables. - It has been used to classify participants into outcome risk categories by first identifying the biological markers and cut points that best differentiate across participants. - These have been used to define AL categories (e.g., high, intermediate, low) and tertiary outcomes (e.g., mortality).

Grade of membership	- The multivariate reduction technique that identifies heterogeneous groups of combinations and their value zones is then used to estimate whether a participant matches a defined combination and the degree of their membership in one of these combinations. - Individualized weights are then used to compare participants against specific pre-defined profiles (e.g., low neuroendocrine and high metabolic combinations versus high neuroendocrine and high cardiovascular).
k-Means cluster analysis	- The multivariate reduction technique identifies homogeneous groups of cases sorted into one of any specified number of clusters. - Once sorted using the nearest centroid algorithm, these clusters serve as groups (e.g., recovered, non-recovered, and fatigued) that can then compare in terms of allostatic load levels.
Genetic programming based symbolic regression algorithms	- Regression and classification technique involving an evolutionary computer simulation that processes programs built from specified primitives (logical or arithmetic operators such as ‘‘+, _, *, /’’) that are a good fit to a given dataset. - This is a computer-intensive approach ultimately used to understand the dependency of one variable on several others (e.g., AL biomarkers and chronic fatigue syndrome symptoms).

Table 2. Summary of available AL algorithmic formulations and statistical techniques. Source: Juster et al., 2010.

2.5.4 Psychosocial stress

A significant stressor that has gained prominence in recent times is psychosocial stress. In simpler terms, psychosocial stress emanates from social interaction with our environment. Individuals facing social threat situations, including social evaluation or exclusion, may experience psychosocial stress. Hence, psychosocial stress may create dysfunctional intrapersonal emotional and behavioural states that result in destructive interpersonal networks and social connections (Laelia et al., 2006). General-life psychosocial stress may arise from major life events (e.g., divorce, job loss), daily hassles, and interpersonal, familial, and societal interactions (Serido et al., 2004; Slavich, 2016). Workplace psychosocial stress also remains an unrelenting source of stress with grave individual, societal, and economic implications. It is further complicated by the reality that most adults spend a greater portion of time at work, so they are increasingly susceptible to psychosocial stress inherent to their jobs; hence, it is recognised as an issue with significant ramifications (Peter & Siegrist, 1999).

Work-related psychosocial stress may best be described as the adverse reaction, including physical and mental strain, which individuals exhibit due to excessive pressure or demands experienced at work (Kinman & Wray, 2013). The Canadian Center for Occupational Health and Safety (CCOHS, 2018) describes work-related psychosocial stressors as agents that elicit deleterious physical, behavioural, and psychological responses due to conflict between job demands, autonomy, and control available to the individual to execute such demands. An important implication of this unique stressor is the risk of psychosocial job strain, a measure of the balance between psychological demands and the control or influence one wields over such demands (Wilkins & Beaudet, 1998).

2.5.5 Theories of work-related psychosocial stress

Psychosocial workplace stressors and job strain are commonly explained using the demand-control theory (Karasek, 1979) and the effort-reward model (Siegrist, 1996). The demand-control model focuses on the interplay of psychological demands (workload) and control (decision latitude or autonomy). High strain resulting in the most stress occurs when job demands exceed an individual control or capacity for decision-making. A third component, perceived social support at the workplace, was later incorporated into the demand-control model (Johnson & Hall, 1988). Perceived social support from colleagues and superiors may contribute to improved confidence and team integration, thus, mitigating the harmful effect of work-related stress. The effort-reward model emphasizes the balance between effort (keeping commitments, meeting deadlines) and expected reward (job benefits, job security, promotion opportunities). Based on this model, when an imbalance between the effort expended and reward received exists such that effort surpasses reward, high strain occurs, producing stress. Both models highlight complementary aspects of a stressful psychosocial work environment. The demand-control-support model focuses on task control, participation and buffering effect of social support, while the effort-reward model focuses on reward and contractual fairness in employment (Karasek, 1979; Siegrist, 1996).

Among other models considered, one of the earliest recognized is the "person-environment fit" model (Caplan et al., 1975). This model describes the stress-strain relationship as a mismatch between job demands and requirements versus individuals' motives or perceived capacity to meet such demands. Within this model, high strain develops when an individual motive or capacity fails to meet the job demands. This model uniquely considers individual differences in perceptions, skills, and tolerance for job pressure as key modifiers of the stress-strain relationship.

Based on these models and contemporary research, here are some of the psychosocial work-related stressors that have been identified: job demands (work pressure, excessive workload, inflexible and unpredictable work hours), role conflict/ambiguity, poor decision latitude, interpersonal demands (personality conflicts, leadership style, group pressures), grievances due to high effort and low reward, poor communication, work-home conflict, work-life imbalance, job insecurity, toxic work climate, poor organizational system, procedural and relational injustice (Baker, 1985; Cox, 1993; Nieuwenhuijsen et al., 2010; Quick et al., 1997).

2.5.6 Work-related psychosocial stress, organization and societal consequences

The impact and cost of work-related psychosocial stress at organizational and societal levels are evident. For example, there is clear evidence linking psychosocial stress (i.e., high job strain) to higher levels of sickness absence, presenteeism, absenteeism, short and long-term disability, job turnover, and early retirement for individuals regardless of occupation (Hassard et al., 2014; J. Park, 2007; Schmidt et al., 2019; T. Yang et al., 2016). Similarly, increased organizational operating costs (e.g., higher insurance premiums), productivity loss, and poor job performance have been linked with greater exposure to psychosocial stress at work (Hassard et al., 2014; J. Park, 2007).

At the societal level, the consequences of chronic psychosocial stress at the workplace, including the development of chronic disease, may contribute to rising health costs and strain the healthcare system. Rising stress levels may slow economic growth and productivity and lead to unexpected redirection of funds to tackle growing healthcare costs, all of which may negatively impact the gross domestic product (Gadinger et al., 2012; Hassard et al., 2014)

2.5.7 Work-related psychosocial stress and its adverse outcomes

The impact of psychosocial stressors is evident, especially on the individual level, regardless of organization size, experience on the job, or position within the organization. Moreover, compelling evidence links a wide range of behavioural, physical, and mental health outcomes to prolonged exposure to job strain caused by psychosocial stress (Hassard et al., 2014; Quick & Henderson, 2016).

Psychosocial work stress and behavioural outcomes

Work-related psychosocial stress has been shown to trigger harmful behaviours such as smoking, alcohol abuse, and physical inactivity amongst strained workers (Griep et al., 2015; Heikkilä et al., 2012; Kouvonen et al., 2005). For example, Kouvonen and colleagues found that being a smoker was 1.13-fold greater among men and 1.28-fold greater among women reporting low rewards for effort rendered than their male and female colleagues with better rewards, respectively (Kouvonen et al., 2005). Concerning alcohol consumption, Heikkila et al. (2012) meta-analysis applying pooled data from 12 studies revealed that heavy drinkers had higher odds (OR 1.12, 95% CI: 1.00, 1.26) of job strain compared to moderate drinkers. Finally, on physical activity and psychosocial stress, findings from Griep et al. (2015) study indicate that men (OR 1.34, 95% CI: 1.09,1.64) and women (OR 1.47; 95% CI: 1.22,1.77) who reported high job strain were more likely to be physically inactive than their counterparts in the low strain groups after adjustments for age, education, and hours worked.

Psychosocial work stress and physical health outcomes

Niedhammer et al. (2008) cross-sectional study based on a national representative sample of 24,486 working-class French men and women investigated workplace psychosocial risk factors and self-reported health outcomes. Their survey findings revealed that low decision latitude, high job demands, and low social support were significantly linked to poor health, sickness absence, and work injury in men and women after adjusting for other job-related risk factors.

Chandola et al. (2006) cohort study examined the relationship between exposure to work-related psychosocial stress and the risk of developing metabolic syndrome in a group of civil servants prospectively (over 14 years). After adjusting for health behaviours (smoking habit, physical inactivity, poor diet, and alcohol intake) throughout follow-up, they found that higher exposure to work-related stress elevated the risk of metabolic syndrome in a dose-response manner (Chandola et al., 2006).

Regarding musculoskeletal disorders and work-related psychosocial stress, Lang et al. (2012) meta-analysis of 50 longitudinal studies revealed a significant relationship between both variables. Pooled ORs ranged from 1.15 to 1.66, indicating a pattern where psychosocial workplace stressors elevate the risk of musculoskeletal disorders, especially lower back and neck/shoulder symptoms. These psychosocial factors were high job demands, low job control, and monotonous work (Lang et al., 2012).

Clays et al. (2007) investigated the impact of psychosocial job strain (high psychological demand and low job control) on 24-hour ambulatory blood pressure in a subsample of 89 Belgian middle-aged men and women. Their findings showed that participants with perceived job strain reported significantly higher blood pressure at work, at home, and during sleep compared to their colleagues with little or no perceived job strain (OR 3.28, 95% CI:1.58, 6.81). Moreover, this finding remained significant even after accounting for gender, age, body mass index, smoking, physical job demands, and stress outside work. Other studies have corroborated the link between chronic work-related psychosocial strain and the elevated risk of hypertension (Markovitz et al., 2001; Radi et al., 2005).

Pikart & Pikhartova (2015) conducted an umbrella review that synthesized evidence from 37 systematic reviews (conducted after the year 2000) exploring the relationship between psychosocial stressors and the risk of cardiovascular disease (CVD) development and associated mortality. Evidence from the reviews focused on psychosocial work-related stress and job strain (17 out of the 37 eligible review studies) suggests that psychosocial work stressors, especially job demands, played a significant role in developing ischemic and coronary heart disease (Pikart & Pikhartova, 2015).

Psychosocial work stress and mental health outcomes

A common consequence of psychosocial work-related stress is burnout (Borritz et al., 2005; Lindblom et al., 2006). Borritz et al. (2005) conducted a 3-year prospective analysis on the effect of psychosocial work-related factors on burnout. Amongst the 952 participants spanning different service industries, they found that psychosocial factors, including high role conflict, low control/predictability, and a poor chance of career progress, amongst other factors, prospectively predicted burnout. Lindblom et al. (2006) cross-sectional study also corroborated this finding. They revealed that psychosocial work stressors like low control and high workload were significantly linked to high levels of burnout after considering individual emotional states.

Stansfeld and Candy (2006) performed a systematic review and meta-analysis on 38 longitudinal studies investigating the effect of psychosocial work stressors on mental ill-health. Most important among their findings is the enduring association between job strain and risk for general mental disorders. In particular, the meta-analysis revealed that high Job demands, decision latitude and authority, job insecurity, and effort-reward imbalance moderately elevated the risk of psychological distress, depressive symptoms, and anxiety (Stansfeld & Candy, 2006)

Evidence linking psychosocial stress in the workplace and the risk of depression was synthesized by Bonde's (2008) systematic review. Data from 16 studies with a combined sample of approximately 63,000 employees revealed that perception of psychosocial workplace stress was linked with increased susceptibility to depressive symptoms or major depressive episodes. Furthermore, relative risks reaching 1.5 were recorded, with associations between job strain and depression onset substantial amongst men (Bonde, 2008).

2.5.8 Work-related psychosocial stress and its biological embedding

Job strain, a consequential product of work-stress exposure, may significantly alter physiological and behavioural stress responses, leading to neurologic and somatic dysregulation (McEwen & Seeman, 1999; Schnorpfeil et al., 2003). The AL model may elucidate how chronic exposure to psychosocial stressors at work becomes biologically embedded at cellular and supra-cellular levels to cause a significant health impact.

There has been growing appreciation and operationalization of the AL concept as a possible biological warning system of the cumulative consequence of job strain in working populations (Mauss, Li, et al., 2015). As a result, various researchers have applied different combinations of primary and secondary mediators of allostasis to objectively measure the cumulative effect of work-related stress experiences within their respective samples

(Bellingrath et al., 2009; Mauss et al., 2016; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003; J. Sun et al., 2007).

Schnorpfeil et al. (2003) investigated the objective health status (i.e., the AL) of 537 industrial workers and the relationship with work stressors, including job demands, decision latitude, and social support. The ALI that captured the participants' AL included systolic and diastolic blood pressure, HDL cholesterol, DHEAS, and glycosylated haemoglobin. Their findings showed that in older workers (age > 45 years), job demands significantly elevated their AL; social support and decision latitude failed to meet significance (Schnorpfeil et al., 2003).

Sun et al.'s (2007) cross-sectional study looked at job strain and AL amongst 1219 healthy workers. The authors used an ALI comprising 13 biomarkers, including blood pressure, cholesterol, and inflammation markers. Their findings showed that low decision latitude (β -.28, p <.05) and high job demands (β .23, p <.001) significantly raised the AL within the sample of workers after controlling for age, gender, education level, marital status, personality, physical exercise, alcohol consumption, and smoking status (J. Sun et al., 2007).

Bellingrath et al. (2009) explored the relationship between psychosocial work-related stress and AL among young female school teachers. ERI, chronic stress experience and an ALI comprising 17 biomarkers (e.g., cortisol, HDL, fasting glucose level) were assessed in 104 teachers. Their finding showed that women reporting a high ERI had significantly higher AL than women reporting a low ERI (t -2.26, p = 0.026, d = 0.59).

Mauss and colleagues cross-sectional study utilized the ALI (15 biomarkers comprising primary and secondary mediators) to assess the wear and tear from chronic work stress exposure (Mauss, Jarczok, et al., 2015). With a focus on ERI, Mauss et al. found that among a sample of 3798 German industrial workers, individuals with greater work-related stress (high ERI) had significantly higher ALI scores (OR 1.19, 95% CI: 1.00, 1.42) when compared to individuals reporting lower stress levels. Moreover, their finding remained consistent after using a modified ALI consisting of the "big five" parameters: diastolic blood pressure, glycosylated haemoglobin, low-density lipoprotein, waist circumference, and HRV) and accounting for confounders (OR 1.27, 95% CI: 1.05, 1.54). Mauss and colleagues corroborated these findings by replicating the study in a sample of 19,274 German workers. Similarly, employees reporting significant work stress captured by elevated ELI had significantly higher AL than their less-stressed colleagues (Mauss et al., 2016).

2.6 Firefighters and their work environment

Firefighters are professionals trained rigorously in firefighting; this includes putting out dangerous fires that threaten or harm life (human and animal), property, and the environment. Fire suppression includes structural and wildfire suppression. Wildfire suppression requires various skills and tactics (e.g., special equipment like aircraft) to suppress fires in wildland areas, including forests.

Throughout their careers, firefighters are provided extensive training and are evaluated to ensure they have the skills for safe operations. In addition, firefighters are trained to carry out rescue services, emergency medical procedures, and disaster management. For example, rescue services may involve structural collapse, elevator emergencies, vehicular accidents, and energized electrical line emergencies (Jahnke et al., 2012). Firefighters also frequently get involved in emergency medical services; however, they mostly render primary first-aid during emergencies and work with emergency medical technicians responsible for administering medical support.

Most fire departments/brigades share a para-military hierarchal structure with the firefighters working in basic units known as “crew” or “platoons”, depending on jurisdictions. Rank ranges from fire service chiefs to probationary firefighters (Engel, 2020), although the ranking nomenclature may differ between jurisdictions or countries. Captains typically oversee the basic units and station duties and are in charge of events at the scene of a fire incident. The fire chief is the highest-ranking officer in the fire department.

In most urban areas, firefighters are recruited for full-time positions and work within rotating shifts. These duty shifts are usually structured to cover a full day (24 hours). The number of hours needed to work per week differs across jurisdictions; however, shifts rotate, and firefighters are usually entitled to days off during a workweek. On the other hand, rural areas, smaller towns, and villages may employ the services of volunteer firefighters and departments. The volunteer firefighters may be unpaid or renumerated with small salaries; often, they work other jobs besides firefighting.

Chapter 3

THE ALLOSTATIC LOAD MODEL: A THEORETICAL FRAMEWORK FOR INVESTIGATING THE MULTI-SYSTEMIC IMPACT OF CHRONIC WORK-RELATED PSYCHOSOCIAL STRESS EXPOSURE AMONG FIREFIGHTERS

3.1 Abstract

Psychosocial factors are recognized as a significant source of stress in the workplace, and chronic exposure to such stressors is linked to deleterious health outcomes. Certain groups experience psychosocial stress to a greater degree due to specific inherent factors. Amongst these groups, evidence shows a substantial degree of stress experienced by firefighters.

The degree to which these psychosocial stressors affect firefighters may be explained using the “allostatic load” model, which elucidates the possible connection between exposure to workplace stressors and stress-related dysregulation across various physiological systems with subsequent development of chronic disease with time.

This article proposes integrating the allostatic load (AL) model within a research framework centered on firefighters’ health and wellbeing. With the application of the proposed model, our fundamental goal is to develop a comprehensive framework to objectively investigate psychosocial stress and the process leading to health deterioration among firefighters. In addition, we discuss potential challenges and opportunities presented using the AL framework within this professional group.

We hope that the insights gained from this work will establish the applicability of the AL framework within stress-disease research in firefighters and provide a reliable approach to primary disease prevention in firefighters and first responders.

Keywords: Allostatic load, workplace, psychosocial stress, firefighters, framework

3.2 Background

Firefighting has been heralded as a noble profession with high social recognition and honour. Unfortunately, despite the admiration surrounding firefighting, it is a highly hazardous occupation as firefighters are frequently exposed to life and death situations. Firefighters are expected to tackle dangerous situations with bravery as others flee. Further, firefighters deal with the physical demands of their job and increasing climate-related events. In addition, beyond fire suppression, firefighters engage in non-fire emergencies, for example, medical emergencies such as drug overdoses and vehicular accidents (Fisher & Etches, 2003; Jahnke et al., 2016). Hence, it is no surprise that firefighting consistently ranks amongst the most dangerous and stressful occupations in North America (Renzulli, 2019; G. Williams, 2022).

Additionally, work-related psychosocial stress, an enduring and potent threat to the health and wellbeing of firefighters, has commanded attention in recent decades. In firefighting, work-related psychosocial stress may be described as work events and characteristics, including social interactions, that produce psychological strain (Ganster & Rosen, 2013). These stressors may appear through job demands, interpersonal relationships, organizational systems, and work environment/culture (An et al., 2015; Payne & Kinman, 2019; Saijo et al., 2007). The constellation of the day-to-day job demands and other work-related psychosocial stressors experienced by firefighters puts them at significant risk, including poor job performance and adverse behavioural and health outcomes (Bongkyoo Choi, Dobson, et al., 2016; Isaac & Buchanan, 2021; Jang et al., 2016; Soteriades et al., 2019).

Given the rise in adverse health outcomes (such as short- and long-term disability, absenteeism, and chronic illnesses) and the escalating cost to firefighters and public safety, there is an urgent need to address workplace stressors that impact health and wellbeing. However, despite mounting evidence suggesting a significant association between psychosocial stress and adverse health outcomes, the underlying process still eludes our comprehension. Due to the complicated nature of this relationship, a theory-driven framework provides the best approach to elucidating this phenomenon. The AL model (McEwen & Stellar, 1993) offers an innovative and reliable framework for investigating and understanding the cumulative biological imprint of chronic psychosocial stress exposure in firefighters.

The primary purpose of this article is to introduce the AL framework and explore its practicality for scientific inquiry into stress, its response, and outcomes among firefighters. Along with this objective, workplace psychosocial stressors and factors that may potentially influence the pathophysiological mechanism leading from stress exposure to health outcomes are discussed in detail. In order to meet these objectives, the article proceeds as follows. First, the various types of stressors commonly reported amongst firefighters are identified. Next, a review of work-related psychosocial stress and its adverse outcomes for firefighters and society is provided. Thirdly, the AL model is introduced, and the framework's utility for studying work-related stress and its cumulative effect on firefighters' health and wellbeing are outlined. After this, we describe factors that may play a significant role in the stress-AL-outcome relationship. Finally, we discuss methodological barriers and opportunities in applying the AL framework within this professional group.

3.3 Types of firefighter stressors

Stressors prevalent amongst firefighters can be grouped into two main categories: physical and psychosocial. In addition to physical stress from fire suppression, firefighters endure physical stress from exposure to work-related factors like fire-related injuries, structural collapse risks, equipment failure, exposure to contaminants from combustion products, and the rare risk of vehicular accidents. Also, since firefighters respond to medical emergencies and disasters, they experience physical stressors that threaten personal safety, for example, needlestick and sharps injuries, patient violence, exposure to toxic substances, and infectious respiratory diseases (G. A. Durand et al., 2021; Fisher & Etches, 2003).

Further, firefighters may experience traumatic stressors, which include cases where the perceived magnitude of a physical and/or psychosocial stressor exceeds a significant severity threshold. Characteristics that may foster the likelihood of an exposure crossing the traumatic threshold include witnessing the injury, or death of victims, or fellow firefighters and the experience of dealing with victims of fire, violence, accidents, and disasters (Beaton & Murphy, 1995; Fisher & Abrahamson, 2002; Fisher & Etches, 2003). As might be reasonably expected, traumatic stress experience puts firefighters at higher risk of post-traumatic stress disorders (M. N. M. Salleh et al., 2020) and vicarious trauma, or compassion fatigue (i.e., stress emanating from exposure to a traumatized person; Cocker & Joss, 2016; Fisher & Etches, 2003).

Due to decades of research, there is considerable evidence on the prevalence of physical and traumatic stressors and their consequences, primarily because of their link with health-related outcomes such as musculoskeletal, respiratory, and traumatic stress disorders (Guidotti, 1992; Jahnke et al., 2016; Mustajbegovic et al., 2001; Regehr & Leblanc, 2011). Consequently, great strides have been made in policies, training, and protective equipment to mitigate the impact of physical and traumatic stressors on firefighters.

3.3.1 Psychosocial workplace stress

Firefighters have a unique work schedule, often consisting of a traditional 24-hour shift and taking two days off (the “24-48” work schedule); however, in exceptional cases, 24-hour shifts may extend beyond the allocated schedules (Bongkyoo Choi, Schnall, et al., 2016). During these shifts, firefighters often face frequent emergency alarms that may promote a hypervigilant state with readiness for potential danger. In other instances, especially on a slow day, their shifts may get boring (Murphy et al., 1999). However, the “24-48” work schedule and 24-hour shift duration may lead to varying levels of stimulation causing sleep disruption, sleep inertia, sleep deprivation, fatigue, and anxiety (Barger et al., 2009; Haddock et al., 2013; Murphy et al., 1999). In addition, work-life balance and marital satisfaction may suffer because of the unusual work schedule with extended work hours (Shreffler et al., 2011).

Further, most firefighting work environments in North America and other parts of the world employ a paramilitary leadership style with a “chain of command” structure (Murphy et al., 1999). This leadership style may inadvertently create challenges in communication leading to interpersonal conflicts, power struggles, disagreement/insubordination with leadership, or, in worst-case scenarios, result in an authoritative and toxic work environment/climate (Beaton & Murphy, 1993). In addition, the paramilitary training method may encourage the sort of bravado that exposes firefighters to risk-taking and fatal mistakes (Fisher & Etches, 2003). Since firefighters depend on the leadership and combined effort of the entire platoon (crew cohesion; Driessen, 2002), there is often an expectation of bravery and commitment from each team member. The downside of such expectation is the possibility that firefighters struggling with job demands, or other issues, may choose not to seek help, speak out for fear of stigmatization, or be ostracised (Banes, 2014; Beaton & Murphy, 1993).

In addition, various factors have begun to emerge that have complicated the work environment of firefighters. As mentioned earlier, firefighters, especially those working in urban areas, have observed increased job demands, role conflicts and ambiguity due to their growing involvement in emergency medical services and other demanding activities. As a result, in addition to fire-suppression skills, they must be well-versed in life-saving skills/techniques that require time urgency, decision-making readiness, exposure to threats or harmful situations, and preparedness to deliver tragic news to the family of victims (Murphy et al., 1999). Further, changing demographics, rapid urbanization, climate change, and cuts in funding have added more demands on time, effort, and capacity to an already over-burdened profession. Despite the increase in job demands experienced within firefighting, pay and benefits do not grow in a matching fashion, which can lead to effort-reward imbalance, job insecurity concerns, and burnout (Ângelo & Chambel, 2013; Lourel et al., 2008; Rajabi et al., 2020).

3.3.2 The enduring impact of psychosocial stress on firefighters

Due to the repeated exposure to work-related psychosocial stressors, it is not surprising that firefighters encounter a high risk of adverse physiological, mental health, behavioural and interpersonal challenges (Fisher & Etches, 2003; Igboanugo et al., 2021). Not only do firefighters have an increased risk of occupational injuries, but the physiological burden of exposure to these stressors (acute and chronic) also increases the risk of adverse health conditions such as cardiovascular disorders (Bongkyoo Choi, Schnall, et al., 2016; Shin et al., 2016), musculoskeletal difficulties (M. G. Kim et al., 2013, 2016; Soteriades et al., 2019), gastrointestinal issues (Jang et al., 2016, 2017), and sleep disorders (Haddock et al., 2013; Yook, 2019).

Similarly, continuous exposure to workplace psychosocial stress has been linked to several undesirable mental health outcomes such as burnout (Makara-Studzińska et al., 2020; Smith et al., 2019), post-traumatic stress disorder (Mitani et al., 2006; Saijo et al., 2012), anxiety (Jahnke et al., 2019; Payne & Kinman, 2019), and depression (Saijo et al., 2008; Stanley et al., 2018). In addition, harmful behaviours such as alcohol dependency, or abuse are also associated with high perceived psychosocial stress amongst firefighters (Arbona et al., 2017; Hosoda et al., 2012; J. I. Kim et al., 2018).

At the organizational level, stress-related adverse health outcomes may appear as increased rates of absenteeism, sick days, long-term disability, labour-management disputes, turnovers and early retirements (Fisher & Etches, 2003). In addition, poor performance, inability to attract and retain firefighters, and increased healthcare spending are potential consequences of these health outcomes that might put the public at risk.

3.4 The allostatic load framework: Biological embedding of workplace psychosocial stress

In response to stressful stimuli, a set of highly interrelated adaptive processes are activated, allowing the body to respond to the challenge and maintain homeostasis (McEwen & Wingfield, 2003). The two most notable adaptive stress response systems are the hypothalamic-pituitary-adrenal gland (HPA) axis and the sympathetic-adrenal medullary (SAM) system (Chrousos, 2009; Kyrou & Tsigos, 2009; McEwen, 1998). Stimulation of the HPA axis and the SAM system leads to the release of vital hormones (such as cortisol and adrenaline). These vital hormones act as primary mediators responsible for generating and redistributing energy resources by initiating a cascade of physiological events in different, but interconnected, systems required to address stressors, including the cardiometabolic (e.g., elevated blood pressure, glucose regulation) and immune (e.g., redistribution of leukocytes and release of cytokines) systems (Chrousos, 2009; Godoy et al., 2018; Kyrou & Tsigos, 2009).

Maintaining homeostasis (stability of physiological systems) requires adaptable and flexible adjustments to meet contextual demands (Doan, 2021; Seeman et al., 1997). These adjustments are supported by allostasis, which may be defined as the dynamic adaptive response process regulated by the brain that preserves physiological stability when met with environmental demands (Juster et al., 2010; Sterling & Eyer, 1988).

Although the various physiological changes caused by stress hormones were refined throughout evolution to play a beneficial role in improving adaptation and performance over the short term (e.g., the "fight, or flight" response), chronic activation of the allostatic systems may become progressively detrimental by causing "wear and tear" (Juster et al., 2010). In addition, repeated perturbations and challenges may lead to dysregulation, given the chronic activation of the allostatic systems (Doan, 2021). Thus, the cumulative biological cost associated with continued attempts by the body to manage stress over the long term has become known as "allostatic load" (AL; McEwen & Wingfield, 2003; Seeman et al., 1997). Hence, the AL model may provide an account of the physiological process that begins with exposure to various stressors experienced throughout life and culminates in adverse health outcomes (Simandan, 2010).

McEwen and Seeman (1999), in their seminal work on the stress-AL relationship, detailed the steps by which high AL culminates in disease. At first, frequent stressors, or chronic exposure to stress burdens the body's adaptive and regulatory systems. Subsequently, the chronic activation of allostasis leads to a series of pathophysiological states representing altered response patterns, including the inability to properly extinguish the physiological stress response, even after the stressor is gone. Finally, due to overuse, or maladaptation, such failure to adapt results in overcompensating and dysregulated biological systems that eventually succumb to disease states (Ganster & Rosen, 2013; McEwen, 1998).

3.4.1 Measuring allostatic load

The strength of the AL model lies in its capacity to measure the cumulative biological burden of acute and chronic stress placed on the body's physiological systems (Buckwalter et al., 2011). The AL model allows us to identify multisystem stress biomarkers chronically operating beyond normal ranges. In measuring AL, various biomarkers (i.e., the AL index, or ALI) that predict pathologic states are compiled and the recorded values are dichotomized according to risk categories (subclinical, or clinical) determined by the sample's distribution of a biomarker (Bizik et al., 2013). The ALI score is then computed by summing all the scores falling into high-risk quartiles recorded as "1" (normal values are scored zero) (Bizik et al., 2013). Regardless of the combination of factors used to determine the ALI, the summary measure of AL is a preferable and greater predictor of long-term health than any individual biomarker (Karlamangla et al., 2002; Seeman et al., 2001).

Based on the theoretical construct of allostatic load, it is conceivable that elevated stress over time will increase one's ALI. This notion has been corroborated by evidence from both cross-sectional (Mair et al., 2011; Mauss & Jarczok, 2021) and longitudinal studies (Clark et al., 2007; Glei et al., 2007; Piazza et al., 2019; Upchurch, Stein, et al., 2015) alike that have applied the AL model. These studies have found significant evidence to suggest that psychosocial stress experience is linked to increased AL scores in the general population. Moreover, along with evidence supporting the link between chronic stress and high AL, extant research affirms that high AL significantly increases the risk of adverse health outcomes (Bizik et al., 2013; Juster, Sindi, et al., 2011; Seeman et al., 1997). For example, among the earliest attempts at operationalizing AL, Seeman et al. (1997) compiled an index of 10 biomarkers, which showed that high ALI correlated significantly with poor health status, including adverse cognitive function. Following this finding, current literature reviews have documented evidence linking elevated AL to adverse health outcomes, including psychiatric conditions, cardiovascular disease, and all-cause mortality (Beckie, 2012; Guidi et al., 2021).

3.4.2 Work-related psychosocial stress and allostatic load

Current evidence points to a strong link between psychosocial stress and significant neurologic and somatic dysregulation in the form of high AL (Juster, Sindi, et al., 2011; Marón et al., 2019; McClure et al., 2015; McLoughlin et al., 2021; Theall et al., 2012). As a result, the growing application of the AL model to help us understand the cumulative consequence of job strain in working populations should not be surprising (Ali et al., 2016; Bellingrath et al., 2009; Mauss et al., 2016; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003; W. Sun et al., 2011). For example, work-related psychosocial stressors (such as effort-reward imbalance, high job demands, low decision latitude/control, and low work safety) have all been found to be positively associated with AL (Bellingrath et al., 2009; de Castro et al., 2010; Mauss et al., 2016; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003; J. Sun et al., 2007). Based on the compelling evidence linking AL and adverse health outcomes in the general population (workers in particular), there is a strong likelihood that work-related stressors elevate the risk for chronic disease through a pathway that involves AL.

3.5 Applying the allostatic load framework in the investigation of work-related psychosocial stress within the fire service

As earlier highlighted, the enduring impacts of work-related psychosocial stress are far-reaching and demand attention. Multiple psychosocial stressors significantly impact firefighter health, leading to undesirable health outcomes, such as gastrointestinal and cardiovascular disorders (Bongkyoo Choi, Schnall, et al., 2016; Jang et al., 2016, 2017; Yook, 2019). Some work-related psychosocial stressors include high psychological job demands, low job control, interpersonal conflict, and working in a toxic work environment (Igboanugo et al., 2021). These stressors are typically unremitting and impact firefighters throughout their careers (Makara-Studzińska et al., 2020; Negm et al., 2017).

Further, the utility and value of subjective stress and health assessment measures, for example, self-report questionnaires (some examples of frequently used measures are listed in table 3), have been widely debated and criticized within certain circles (T. N. Brown et al., 2016). Concerns regarding the reliability and validity of self-report measures have been highlighted as limitations to its use. For example, recall bias may limit the self-report accuracy in capturing past events (Slavich, 2016). Alternatively, some studies have focused on the effect of work-related stress on specific physiological biomarkers, for example, cortisol (Teixeira et al., 2022), heart rate variability (Gomes et al., 2013; Pluntke et al., 2019; Shin et al., 2016; Yook, 2019), and systolic and diastolic blood pressure (Bongkyoo Choi, Schnall, et al., 2016; Kaur et al., 2014). Although both approaches (self-report and target biomarker assessment) play vital roles in stress-outcome assessment, when used individually, they may fall short of elucidating how work-related stress alters the health and wellbeing of firefighters (Ganster & Rosen, 2013).

Despite the progress made in this field, we are yet to account for the plausible mechanisms behind work-related psychosocial stress exposure and the development of adverse health outcomes. Addressing this knowledge gap will create opportunities to counteract workplace psychosocial stressors and minimize their health impact. Hence, based on the available evidence surrounding psychosocial stress and its biological embedding, there is significant value in applying the AL framework to investigate work-related stress within firefighting. The AL model provides a novel and practical approach for (1) a comprehensive understanding of how work-related psychosocial stress and its embedding cause “wear and tear” and (2) deciphering the multi-level dysregulation that consequently leads to adverse health outcomes within firefighters.

Applying the AL framework to firefighters is pragmatic from an investigative standpoint. First, due to the unique psychosocial stressors firefighters experience, which are usually chronic and unabating, the AL model allows us to examine the ongoing systemic effect of such stressors. For example, compared to investigation centered around the assessment of single (candidate) biomarkers like blood pressure (Bongkyoo Choi, Schnall, et al., 2016; Kaur et al., 2014) that provides limited information on specific systems, the AL model consolidates information from multiple systems, thus offering better predictability of stress-related disorders (Juster, Russell, et al., 2016). Additionally, the AL model's attention to subclinical disease supports a paradigm shift in disease prevention from traditional biomedical approaches focusing on managing and treating disease (Beckie, 2012).

Secondly, the Healthy Worker Effect (HWE; a reduction in morbidity and mortality in workers compared to the general population) may be evident in studies investigating chronic diseases in professions with strict recruitment criteria, for example, firefighters (Bernard Choi, 2000). In addition, the HWE may have influenced epidemiological evidence regarding stress and its outcomes amongst firefighters because of the recruitment and retention practices commonly used within the fire service (Bernard Choi, 2000). For example, the recruitment of healthy, resilient, low-risk firefighters lacking comorbidity is typical among fire departments (Bernard Choi, 2000). Hence, it is intuitive to assume that such bias may obscure the effect of work-related stress observed with studies dependent on subjective stress measures or singular biomarker use. The AL model is best suited to deal with this issue since evident changes within multiple systems are identified with the ALI even when firefighters appear, or perceive their health to be satisfactory. Hence, the AL model may effectively detect systemic health changes in an otherwise healthy professional group.

Finally, because AL serves as a multisystem indicator of chronic physiological dysfunction, its framework presents a viable approach to chronic disease prevention among firefighters. Since computing the AL index informs our understanding of the cumulative changes in one's physiological status over time, AL may serve as a biological warning system that identifies systems undergoing significant clinical change, or deterioration (Juster, Russell, et al., 2016). Additionally, since measuring AL allows identifying individuals at risk of adverse health outcomes, it provides a valuable time window to address prevailing stressors and lessen their health-related consequences. Targeted interventions, especially those geared towards health promotion, can be readily applied to improve the health and wellbeing of at-risk firefighters.

3.5.1 Primary and Secondary variables for consideration in the proposed firefighters' AL framework

In addition to our primary variables of interest (work-related psychosocial stress and its association with AL), other factors might impact this relationship. For example, empirical studies have shown that AL progression may be influenced by various general and occupational-specific determinants (Gustafsson et al., 2014).

3.5.1.1 Primary variables within the AL model

The primary variables that constitute the AL model for career health assessment in firefighters include work-related psychosocial stress exposure, allostatic load, and adverse health outcomes. Therefore, the stress exposure, or stressor will be regarded as the predictor variable within this model, while AL, or its likely result (chronic disease) will be the outcome (dependent) variable.

3.5.5.2 Secondary variables within the AL model

The sequence of events from adaptive stress response to AL and adverse health outcomes are dynamic and may be influenced by modifiable and non-modifiable secondary variables. According to the current literature, some non-modifiable factors linked with AL that may be relevant to consider when investigating firefighters include age, sex, and ethnicity (Beckie, 2012). In addition, modifiable factors that may be considered among firefighters that have shown varying degrees of association with AL include psychosocial coping resources and behavioural habits such as physical activity, eating habits, and alcohol intake (Schneiderman et al., 2005; Suvarna et al., 2020).

Age and allostatic load

Compelling evidence shows that AL consistently increases with age (Beckie, 2012; Crimmins et al., 2003; Seeman et al., 2001). For example, data from 22,000 participants in the NHANES study revealed a progressive elevation of AL among those aged 20-60 (Crimmins et al., 2003). The age-AL relationship is expected, given that the multi-systemic change in physiology captured by AL reflects the gradual change in the body's function over one's lifespan (Guidi et al., 2021; Read & Grundy, 2014).

Additionally, as longer-serving and experienced firefighters rise through the ranks and are accorded more responsibilities, they may endure more frequent, or intense work-related psychosocial stress events, with mounting physiological costs as their career progresses (Goh et al., 2020; Regehr et al., 2003). Thus, given that firefighters spend considerable time on the job and mostly retire past the age of fifty-five (King, 2011), both age and length of service will need to be considered when investigating work-related psychosocial stress and its impact on AL amongst firefighters.

Biological sex, gender roles and allostatic load

Biological sex and psychosocial gender roles may independently, or synergistically influence AL (Juster, Pruessner, et al., 2016; Juster & Lupien, 2012; Kerr et al., 2020). Regarding biological sex, extant literature from the working and general population suggests that higher AL is more often found in men (Kerr et al., 2020; Mauss, Li, et al., 2015; Schnorpfeil et al., 2003). A variety of factors could be responsible for the observed sexual dimorphism; most notable among them could be the immuno- and neuroprotective effect from estrogen benefitting women and greater biological responsivity to stress that men tend to exhibit (Kajantie & Phillips, 2006; McEwen, 2002; Y. Yang & Kozloski, 2011)

Juster and Lupien (2012) highlight the importance of gender roles in the stress-AL paradigm; they describe gender as a spectrum of personal traits, identities, and orientations influenced by sociocultural norms and expectations. Gender roles represent an individual's masculine and/or feminine behaviours; masculine roles are characterised as hostile, assertive, competitive, and impatient, while femininity is typically viewed as nurturing and sensitive (Juster, Pruessner, et al., 2016; Kerr et al., 2020). While investigating gender roles and AL, Juster and Lupien revealed that traits associated with masculinity, unlike those typically associated with feminity, were significantly associated with higher AL in both sexes (Juster & Lupien, 2012).

Firefighting remains a male-dominated profession, since they make up at least 90% and 95% of the total population in the US (NFPA, 2020; ZIPPIA, 2022) and Canada (P-SEC, 2021), respectively. Although more women have joined the fire service, they remain in the minority. They are subjected to a hyper-masculine environment that often requires acculturation while navigating gender-influenced attitudes and earning respect from male counterparts (Sinden et al., 2013). Such expectations, coupled with an elevated risk of stress-related conditions linked to their minority status in a male-dominated occupation, imply that female firefighters may record higher AL than their male colleagues. Hence, there is significant value in applying sex- and gender-based analysis when utilizing the AL framework to investigate firefighters; doing so should provide a nuanced and deeper understanding of the stress-AL relationship.

Ethnicity and allostatic load

Ethnicity has previously been shown to influence AL either independently, or along with other variables such as education level and socioeconomic status (Beckie, 2012). Since ethnic minorities may experience discrimination and institutionalised racism more often than their white counterparts, such inimical events may contribute to elevated AL and adverse health outcomes (Peek et al., 2010). Indeed, a study by Geronimus et al. (2006) provided evidence using survey data collected from US adults that revealed black individuals reported higher AL scores than whites after accounting for age and poverty. Unfavourable socioeconomic conditions, systemic racism, a comparative lack of available psychosocial resources, and the burden of intersectionality (i.e., bearing more than one marginalised designation; particularly among black women), may help explain the observed connection between ethnicity and AL (Chyu & Upchurch, 2011; Geronimus et al., 2006; Tobin et al., 2021; Upchurch, Stein, et al., 2015).

In the United States, the demographic make-up for most fire stations typically consists of white (non-Hispanic) males with other racial groups significantly in the minority (Census Bureau, 2019). As elucidated earlier, the minority status of non-white ethnic groups may contribute to additional stress experiences related to discriminatory practices, or hostile work environments (Arbona et al., 2017; Yoder & Aniakudo, 1997). For this reason, considering ethnicity while investigating firefighters, especially in urban areas, is necessary to deconstruct the stress experience, variations in AL progression among the different ethnic groups, and the complex interactions with other variables, for example, the availability of psychosocial resources such as social and administrative support.

Psychosocial resources and allostatic load

Psychosocial resources constitute personal and relational factors that provide intrinsic support for mental and physical health (Wiley et al., 2017). Such resources may materialize intra-individually (e.g., self-efficacy, resiliency), or through inter-individual interactions such as support social relationships (Wiley et al., 2017). In relation to AL, psychosocial resources may either directly prevent stress via proactive coping and promulgating healthy behaviours or indirectly buffer (via mediation or modification) the effect of stress; thus, reducing the physiological imprint of such stressors (Aspinwall & Taylor, 1997; Haly, 2009; Khan & Husain, 2010; Wiley et al., 2017).

Given that social support has been shown to enhance resilience amongst firefighters by providing perceived acceptance and camaraderie, in addition to consistently cushioning the effect of stress exposure in these workers, this psychosocial resource may act as an essential variable influencing the accumulation of AL (Beaton & Murphy, 1993; Regehr, 2009; Regehr et al., 2003). Also, firefighters have shown that self-efficacy and resilience are essential coping resources for overcoming work-related stressors and their outcomes (Makara-Studzińska et al., 2019). Specifically, both resources buffer the effect of stress via behavioural self-regulation (Bandura, 2009; Igboanugo et al., 2021; Makara-Studzińska et al., 2019). In sum, since psychosocial resources act as protective factors in the stress-outcome relationship, it is pertinent to consider them when considering AL progression within firefighters.

Behavioural habits and allostatic load

Increased physical activity has been linked to a reduction in psychosocial stress experience and response, with subsequent dampening of the HPA axis reactivity and release of cortisol (Klaperski et al., 2013; Milani & Lavie, 2009; Rimmele et al., 2007). As well, empirical evidence indicates a significant reduction in AL and its metabolic and cardiovascular outcomes with increased participation in physical activity, irrespective of demography, i.e., sex, race, and age (Gay et al., 2015; Petrovic et al., 2016; Upchurch, Rainisch, et al., 2015; Zhang et al., 2022).

Firefighters are generally encouraged to participate in physical activity, especially between calls while on duty, to maintain the aerobic fitness, muscular strength, and endurance required for their jobs (Pawlak et al., 2015). In sum, participation in voluntary physical activities and meeting fitness guidelines required for firefighting may play a vital protective role against AL in this group. Hence, there is exploratory value in considering the potential influence of physical activity on the stress-AL relationship in firefighters. Additionally, given the assumption of higher fitness levels amongst firefighters, which is a likely contributor to the "healthy worker effect" observed within this occupational group, deciphering the effect of physical activity on AL will provide a more nuanced assessment of the stress impact on firefighter health.

Unhealthy eating habits, such as consumption of high salty, fatty, or sugary food and beverages, contribute to (abdominal) obesity (Paradis et al., 2009) and have been linked to elevated AL and outcomes such as cardiovascular disease (Mattei et al., 2011; van Draanen et al., 2018). Evidence shows firefighters gravitate toward fatty, sugary, and calorie-dense carbohydrate meals (G. Durand et al., 2011; Esquirol et al., 2009). Shift work may also significantly influence firefighters' dietary habits and choices (López-Bermudo & Gómez-Landero, 2021).

Further, evidence suggests that individuals crave and consume comfort foods (i.e., high fat and sugary meals/snacks) to cope with work-related stress (Suvarna et al., 2020). Coupled with emergency calls that may delay, or stop eating and periods of inactivity where firefighters snack out of boredom and stress-eating to deal with a demanding job, unhealthy eating among firefighters warrants investigation into its potential influence on the work-related stress and AL relationship.

Regarding alcohol use, definite conclusions on its effect on AL are still yet to be made. Some studies have recorded a beneficial effect of moderate alcohol intake against AL in men and women (Gallo et al., 2011; Petrovic et al., 2016). However, Crimmins et al. (2009) did not find any association between alcohol consumption and AL. Alcohol consumption within firefighting is often done for social and coping reasons (Jahnke et al., 2014). Unfortunately, problematic alcohol use is prevalent amongst firefighters, and is strongly linked to high job stress (Haddock et al., 2012, 2017; Piazza-Gardner et al., 2014). Based on the findings on the prevalence of problematic alcohol use, attention to the impact of alcohol consumption in response to psychosocial stress and the effect on AL amongst firefighters is warranted.

Figure 6 illustrates the proposed framework of firefighters' work-related stress exposure, AL, and health outcomes. In addition to the proposed AL framework, **Table 3** provides a non-exhaustive list of measures that have been used to provide assessments of the primary and secondary variables among studies with firefighters as participants.

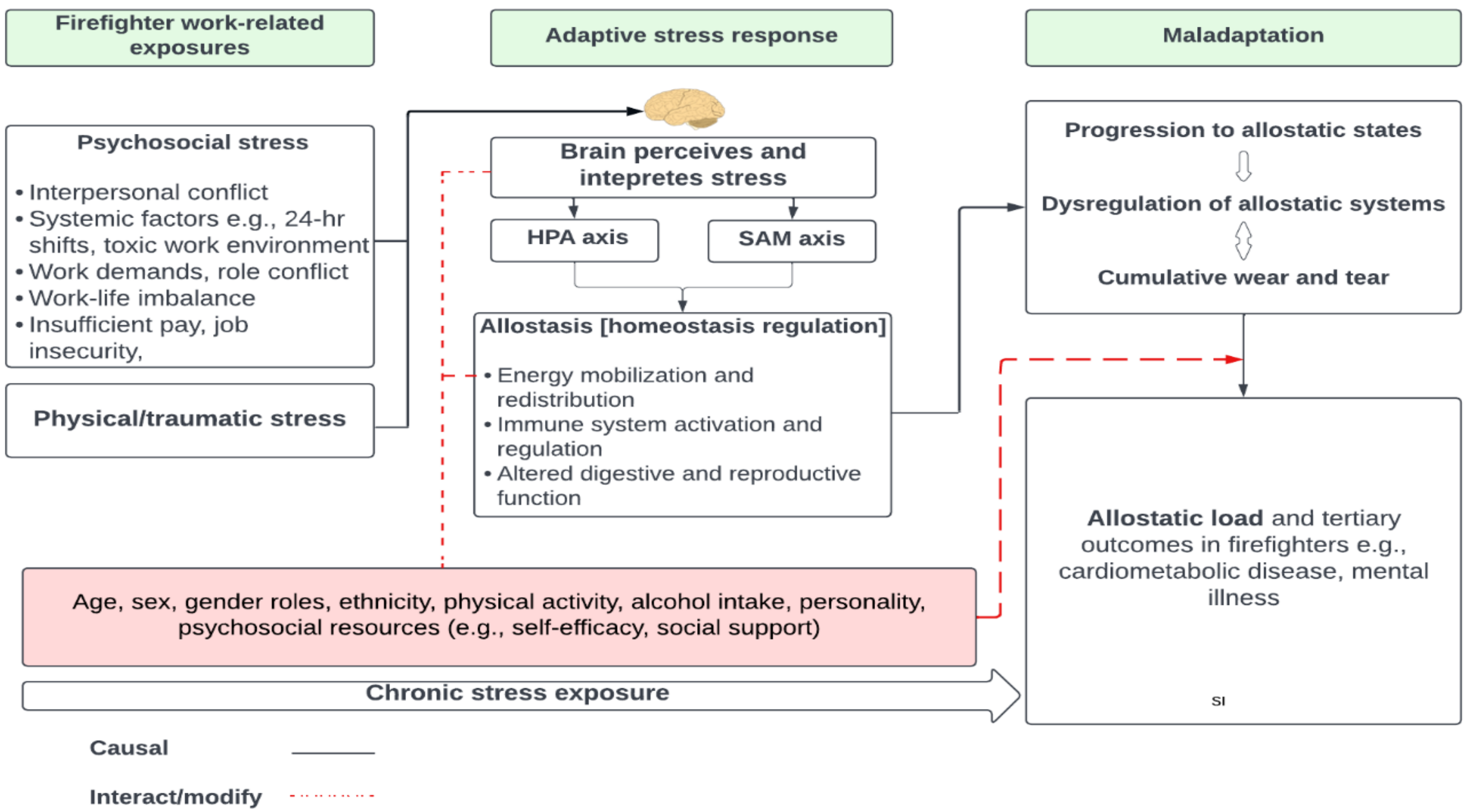

Figure 6. A diagram illustrating the framework for work-related stress exposure, allostatic load build-up, and potential adverse health outcomes in firefighters.

Variables		Measurement tool	Source
Primary Variables	Psychosocial stress	Perceived Stress Scale (PSS-10)	Cohen et al. (1994)
		Sources of Occupational Stress Scale (SOOS-14)	Kimbrel et al. (2011)
		National Institute for Occupational Safety and Health (NIOSH) Generic Job Stress questionnaire	National Institute for Occupational Safety and Health Hurrell & McLaney (1988)
		Job Content Questionnaire (JCQ)	Karasek et al. (1998)
		Effort-Reward Imbalance Questionnaire (ERIq)	Siegrist et al. (2004)
		The Copenhagen Psychosocial Questionnaire (COPSOQ)	Kristensen et al. (2005)
		Guarding Minds at Work	Gilbert & Samra (2010)
		Korean Occupational Stress Scale (KOSS)	Chang et al. (2005)
		Job stress survey (JSS)	Spielberger & Reheiser (1994)
	Allostatic Load (AL) index *	Allostatic load Index (ALI) Different ALI computations: Group (risk quartiles) and norm (clinical thresholds), z-score, and others	Juster et al. (2010) Seeman et al. (1997)
Secondary Variables	Demographic variables: sex, gender, age, length of service, and others.	In-house demographic questionnaires/surveys. Health screening surveys	Created by the study investigator(s)
	Psychosocial resources		
	Social support	Firefighter Social Support Scale (SSS-FF)	Carpenter et al. (2015)
		Social Support Questionnaire	Sarason et al. (1987)

		Social Provisions Scale (SPS)	Cutrona & Russell (1987)
		Multi-dimensional Scale of Perceived Social Support (MS-PSS)	Wilcox (2010)
	Self-efficacy	Firefighter Coping Self-Efficacy Scale (FFCSE)	Lambert et al. (2012)
		The Self-Efficacy Scale	Sherer et al. (1982)
	Behavioural habits		
	Behavioural habits Dietary behaviour/eating habits, physical activity, recreational drug use, and others	In-house questionnaires/surveys; Real-time activity diaries for food consumption, physical activity	Created by the study investigator(s)
		Intuitive Eating Scale (eating habits)	Hawks et al. (2004)
	Alcohol dependency/abuse	In-house questionnaires/surveys	Created by the study investigator(s)
		Alcohol Use Disorders Identification Test (AUDIT)	Saunders et al. (1993)
		CAGE questionnaire	Ewing (1984)

Table 3. Examples of measurement tools and their sources utilized to measure primary and secondary variables. * Assessment not yet used in firefighter research

3.6 Challenges and Opportunities

Despite the AL model's advantages, it is not without its challenges. First, depending on the type and nature of physiological variables collected and measured to constitute the AL index, the data collection process may require significant effort, financial investment, and skillset. Typically, collecting physiological data involving invasive techniques requires expertise and ethical approval. For example, blood collection for measuring parameters like cortisol and glucose requires specialized techniques and professional oversight. Further, primary and auxiliary items used to collect and measure these physiological parameters (e.g., heart rate variability equipment) are costly, and prices quickly increase when investigating large samples. With recent advances in technology, continued application of the AL model will create opportunities to include less invasive, reliable, cost-effective, and validated methods of biological sample collection, especially within the firefighter population.

Regarding the point mentioned above on data collection, the time factor and compliance issue cannot be overlooked. Collection and processing time may be prolonged depending on study type (cross-sectional, or longitudinal), sample size, number of retrieved parameters, and available human resources. For example, specific biological samples (e.g., hair and blood) undergo unique extraction processes in specialized facilities and may require transportation. In some instances, considerable time is spent on such processes, creating logistical challenges. In addition, the measurement frequency of specific physiological parameters (e.g., cortisol assessment in saliva) may burden participants and carry a potential risk of issues with compliance. Such potential logistical bottlenecks must be considered and factored in during data collection, especially when busy professionals like firefighters and their likes are involved.

Another challenge in interpreting findings from studies applying the AL model is the potential lack of agreement between self-report measures and the AL index used to investigate stress (T. N. Brown et al., 2016). A handful of reasons may account for such discordance. One such reason is that individuals may perceive their stress levels as manageable, or minimal; ALI biomarkers capture stress and physiological dysregulation beyond individual perception and consciousness. Also, the lack of agreement could arise from the ineffectiveness of self-report measures to fully capture stress experiences compared to assessments based on the AL model (T. N. Brown et al., 2016). Finally, when considering the timeframe reflected in each assessment, self-report measures often focus on the time around the measurement (e.g., assessment based on the last 3 months). In contrast, the ALI captures the cumulative effect of changes that may have occurred over more extended periods.

Based on these reasons, a lack of concordance may be observed in the case of first responders, especially firefighters, who, by the nature of their job and workplace culture, may exhibit composure and resiliency during psychosocial challenges, which may be reflected in their interpretation of perceived stress. Applying the AL framework will provide a practical opportunity to understand this phenomenon in this unique occupational group.

Various opportunities abound with the AL framework. First, operationalizing the AL model within firefighter research will provide a helpful framework to comprehensively articulate stressful aspects of their psychosocial environment, identify factors that may either contribute to resiliency or weaken it, and detect the progressive impact of stress on their health. Also, operationalizing will allow researchers and clinicians to identify a combination or collection of physiological biomarkers that extensively capture the progression of stress-related chronic conditions prevalent in firefighters, such as cardiovascular disease (Kales & Rielly, 2013).

Furthermore, ensuing research from the application of the AL model will provide greater impetus and interest for empirical inquiry into firefighters and other first responders (e.g., police and emergency medical technicians) that illuminate other aspects of their social and environmental stress experience, including those outside the workplace. Similarly, the AL framework provides an avenue for inquiry into the role of biological sex, ethnic/racial, socioeconomic factors (e.g., income, marital status) and behavioural habits in the psychosocial stress-AL-disease outcome relationship. Additionally, it should motivate research to investigate the interaction effect of occupation-specific factors such as geographical (urban vs rural) firefighting location, rank, years of service, departmental funding on psychosocial stress, and firefighters' outcomes.

Finally, the AL framework offers a reasonable action window to target AL's antecedents to prevent adverse health outcomes for firefighters. With such an opportunity, relevant stakeholders, including researchers, epidemiologists, occupational health experts, and policymakers, obtain relevant information necessary to design interventions, create policies, and allocate resources that significantly improve the health and wellbeing of firefighters.

3.7 Conclusion and Recommendations for future research

Firefighters are an essential group of public servants that put their lives at risk for the safety of others. Moreover, protecting their health and well-being as they spend a considerable portion of their lives serving as firefighters benefit their immediate communities and society. Hence, AL progression and tertiary adverse health outcomes such as cardiovascular diseases linked to duty-related psychosocial stress within this professional group deserve urgent research consideration.

Having outlined compelling evidence spanning nearly two decades on the utility of the AL model in elucidating the complex stress-disease processes in various populations, applying the framework in addressing psychosocial antecedents of stress and their related consequences among firefighters is necessary and recommended. The utilization of the AL model in firefighter research should include experimental investigations and observational studies, especially the longitudinal type that considers various contextual and interacting factors beyond what this study provides to provide a comprehensive understanding of the health implications of AL in this occupational group.

As interest grows and the operationalization of the AL framework gains momentum, there should be a consolidation of the process of retrieving biomarkers, development of improved analytical equipment, and standardization of AL biomarkers used to determine the cumulative physiological consequences of stress within firefighters accurately. Such knowledge would be helpful to clinicians and researchers for the advancement of biobehavioural research and practice and develop health-promoting interventions that improve the health and well-being of firefighters and other first-responders.

Chapter 4
MATERIALS AND METHODS

4.1 Study Population

The population considered for this study were Canadian firefighters; however, for the systematic review and meta-analysis on scalp HCC (chapter 5), healthy adults from all walks of life were considered. The systematic review on work-related psychosocial stress in the fire service focused on studies investigating such stressors amongst active firefighters (chapter 6). For the observational studies in chapters seven and eight, the description of the sample of firefighters and the criteria used to recruit them is provided in the following subsection.

4.1.1 The City of Waterloo Fire Rescue Service

The Region of Waterloo (with a population of about 550,000 people) contains the cities of Kitchener, Cambridge, and Waterloo, each of which has a separate Fire Service. In the three major cities within the region, approximately 500 individuals are employed by the various Fire Services; about 420 are involved with fire suppression. Although all Fire Services within the region were aware of our ongoing research, only firefighters from the Waterloo Fire Rescue were recruited for the study.

Within Waterloo Fire Rescue, there are about 120 full-time firefighters. After discussions with the administrative leadership (i.e., Deputy Fire Chief) of Waterloo Fire Rescue (WFR) and the local union overseeing active firefighters to ensure that all questions and concerns were addressed, permission was granted, and active recruiting began. An *a priori* sample size calculation based on Cochran (1977) formula using 95% confidence intervals (α = .05), a standard deviation of 0.5, and a 5% margin of error was conducted. Given a population of about 120 active firefighters within the WFR, an ideal sample size would have been 92 firefighters. With this number in mind, information and consent forms (**appendix A**) and detailed participant preparation letters (**appendix B**) with potential dates for participation were circulated. Along with being involved with fire suppression activities in the region, inclusion criteria included:

a) firefighters who were not presently undergoing medical treatment for a diagnosed health issue that may have influenced the physiological measures being gathered; for example, medication for managing diabetes, or hypertension.

b) firefighters who were not presently diagnosed with a mental health illness that may have influenced the physiological measures being gathered, for example, major depressive disorder.

In the first phase, which commenced in the fall of 2019, 64 active firefighters participated in the data collection exercise despite a significant recruiting effort. Further, out of the 64 participating firefighters, one firefighter did not complete the questionnaire and was excluded. During the second phase, which took place a year after, in the fall of 2020, only 51 (80%) active firefighters from the first phase participated. Notably, two new firefighters participated; however, their data was not used for the longitudinal analysis, but kept as part of the data set for future longitudinal analysis. The 13 firefighters that did not participate in the second round of data collection were older, male firefighters (average age of 47 years) with an average of 17 years in service.

4.2 Data collection team

For both systematic reviews (chapters 5 and 6), an investigative team comprising myself, research assistants, and my supervisor performed the data collection, which involved a rigorous and systematic search of the literature for eligible studies meeting the inclusion criteria. Data collected (studies gathered) were shared between investigators, and the team discussed and agreed on eligibility. The "method" section in both chapters provides more detailed information on the process of data gathering and inclusion criteria applied.

For the observational studies (4 and 5) in chapters seven and eight, the data collection was performed by a team composed of myself and a research assistant (and sometimes, a trainee assistant). Further, on each day of data collection, the investigative team visited the location (Fire Station 4, Waterloo, Ontario) set aside for that purpose. In order to encourage the participation of female firefighters, the research assistant role was always filled by a female student, or trainee. All members of the research team received ethics clearance to conduct data collection.

4.3 Materials

This section focuses on the materials used in both observational studies in chapters seven and eight. Four major categories of data were sought from the participating firefighters:

general demographic and self-reported health assessments, their appraisal of psychosocial stress, their perceived social support assessment, and their ALI.

4.3.1 General demographics and health assessment

The general demographic assessment was incorporated into the data collection to capture participant demographics. Data including age, gender, length of service, and ethnicity were collected during the first data collection phase (2019). In the subsequent year (2020), marital status, education level, and rank were added to the questionnaire (**appendix C**). Similarly, the health questionnaire, derived from the Canadian Community Health Survey (2016 version), was used to record the self-reported health status of the participating firefighters. Questions covered major health disorders (such as cardiovascular and respiratory diseases), medication and substance use, sleeping habits, and level of physical activity. During the second phase of data collection, Canada was experiencing a COVID-19 pandemic; hence, an assessment was incorporated to capture perceived stress and exposure related to COVID-19 (**appendix D**).

The demographic and general health information collected reflected the current state of the literature on stress and AL and considered feedback received during preliminary consultations with firefighters. The aim was to retrieve demographic and health characteristics that may have impacted our study findings. By accounting for these factors, we hoped to provide clarity and context for the findings from the study.

4.3.2 Social Support assessment

The choice of social support assessment used in this study was based on the desire to capture core features of the concept, including support network resources, support behaviour, and subjective appraisals of stress (Carpenter et al., 2015; Zimet et al., 1988). Therefore, we applied two social support assessments: the Multi-Dimensional Scale of Perceived Social Support (MS-PSS) developed by Zimet et al. (1988) and the Social Support Scale for Firefighters (SSS-FF) developed by Carpenter et al. (2015).

The MS-PSS is a widely used instrument that measures social support with good reliability and validity. Along with the relative simplicity and brevity associated with the MS-PSS, its core strength is the option it allows users to consider their significant other, family, and friends as separate sources of support. The separation of support by relationship provides the opportunity to examine the relative importance of each relationship. Hence, it permitted the modification of the scale in a manner appropriate for our study (**appendix E**). In particular, we chose to remove those items from the MS-PSS that specifically address social support from friends because the SSS-FF directly measures the influence of firefighter colleagues (see below).

The originators of the SSS-FF developed the scale to assess the level of social support that firefighters feel they have received from their colleagues (**appendix F**). However, given the unique nature of their occupational environment (that is, professional firefighters will often eat, work, socialize, and rest together during their shifts), we thought that adding the SSS-FF would provide a more accurate assessment of this particular factor.

4.3.3 Appraisal of Psychosocial Stress

The most common approach to studying occupational stressors involves using scales that capture a variety of stress-related variables likely to be shared across several occupations. Our primary motivation was to apply the Perceived Stress Scale (PSS), a widely accepted questionnaire developed by Cohen & Williamson (1988). The PSS captures an individual appraisal of perceived stress and how it impacts their lives. Since the PSS is regularly used for stress appraisal and has been used in other firefighter samples, making it possible to compare other firefighter samples and other professional groups, we adopted the scale for our analysis (**appendix G**).

In addition to the general-life measure provided by the PSS, an occupation-specific scale was adopted to adequately capture work-related psychosocial stressors relevant to firefighters. We applied the Sources of Occupational Stress scale (SOOS-14), a 14-item inventory developed by Kimbrel et al. (2011). The SOOS-14 measures psychosocial stressors specific to firefighters (e.g., conflict with colleagues, financial strain, and feelings of isolation from family due to work demands) over the previous ten shifts. The scale scoring was modified, i.e., items were scored on a 3-point Likert scale rather than a 5-point to mitigate respondent fatigue (**appendix H**).

4.3.4 Allostatic Load Index (ALI)

Given the nature and number of biomarkers collected to determine AL in earlier reports, concern was raised regarding whether such an approach might provide specific logistical barriers (e.g., high cost and limited throughput) for applying the ALI to occupational settings. However, results from the Mauss, Jarczok, & Fischer (2015) study (and subsequent work from the same group, [Mauss et al., 2016]) provided evidence showing that the five chosen variables (the "big 5") have a significant and robust correlation with workplace psychosocial stress. Consequently, the ALI used for the study was designed using four of the variables proposed by Maus and colleagues: diastolic blood pressure (DBP), glycosylated haemoglobin (HbA1c), low-density lipoprotein (LDL), and HRV. In addition to the noted parameters, scalp hair cortisol concentration (HCC), systolic blood pressure (SBP), high-density lipoproteins (HDL), and waist-height ratio (WHtR) were added to the ALI.

The decision to include four parameters from the "big 5" proposed by Mauss, Jarczok, & Fischer (2015) and the other four biomarkers was based on available resources and supporting literature. The choice to include DBP, HbA1c, LDL, HDL, and SBP into our ALI was based on their utility as potent markers of cardiometabolic functioning, the psychosocial stress response, and AL, which have been well-established in the extant literature (Duong et al., 2017; Li et al., 2007; Seeman et al., 1997; van Dijk & Buwalda, 2008). The assessment of HbA1c was picked over fasting blood glucose, or postprandial plasma glucose because it is a preferred indicator for systemic glucose exposure and reflects the mean glycemic values in the previous 8-12 weeks (Ketema & Kibret, 2015).

The analysis of HRV is widely used to determine the status and adaptability of the autonomic nervous system (ANS) (Thayer et al., 2012). An individual's HRV represents the variation in time between each heartbeat. Typically, in a state of unrest, or stress leading to sympathetic ANS activation, heart rate (HR) increases, and the variation between heartbeats reduces; in contrast, in a state of relaxation, parasympathetic dominance lowers HR and increases HRV (Uusitalo et al., 2011). Hence, low HRV is a reliable marker of ongoing neuroendocrine dysregulation and is associated with elevated AL and risk of all-cause mortality (Thayer et al., 2012; Viljoen & Claassen, 2017). Also, HRV has shown utility as a measure of work-related psychosocial stress assessment (Jarczok et al., 2013; Mauss, Jarczok, et al., 2015). Mainly, our decision to incorporate HRV measured by the time-domain measure RMSSD (root mean square of differences between successive R-R intervals) into the ALI was supported by evidence from Vlijoen and Classen's (2017) study and a meta-analysis by Thayer et al. (2012).

The WHtR, which represents the ratio (R) of waist circumference (W) to height (Ht), has been determined to reflect central obesity better and predict morbidity and mortality than other more commonly used biometrics (Ashwell & Gibson, 2014). Further, a systematic review and meta-analysis by Ashwell et al. (2012) concluded that WHtR is a better predictor and screening tool for cardiometabolic risk factors in both sexes than waist circumference (WC) and body mass index (BMI). Further, despite the popularity of BMI and the ability to measure total obesity, it fails to account for muscle mass, sex differences, and overall body composition (Ashwell et al., 2012; Nordqvist, 2022). This limitation may be particularly relevant to firefighters since they must remain physically fit to meet job demands such as lifting heavy equipment and may, in so doing, accumulate muscle mass. The evidence provided by both studies from Ashwell encouraged our use of WHtR.

The choice to measure cortisol from scalp hair was based on evidence supporting its use as a reliable assessment for systemic cortisol concentration and a biomarker for chronic stress (Sauvé et al., 2007; Thomson et al., 2010). In addition, scalp hair cortisol analysis can overcome technical challenges linked with other traditional sampling methods from serum, saliva, and urine (Russell et al., 2015). For example, hair retrieval requires less technical know-how, is mostly unaffected by situational confounders (e.g., the stress of sample retrieval), and the samples are relatively easy to store.

Despite the technical advantages HCC offers, there is still a lack of a standard reference range or value for HCC in the adult population (Russell et al., 2012, 2015). For example, among the physiological biomarkers used to determine the ALI within our sample, only HCC lacks an established normative threshold value (**Table 4**). In addition, there is a need for a reference value to identify firefighters falling into risk categories (i.e., high HCC) to calculate the ALI based on clinical norms. This absence of a standard reference range motivated the systematic review and meta-analysis of the current literature on HCC in healthy adults. Hence, chapter four (study 2) provides more details on the advantages of HCC assessment, the choice of immunoassay analysis, and proposes a standard reference value for HCC in adults.

Biomarker	Threshold value or range	Source
Systolic blood pressure (mmHg)	≥ 130	Alberti et al. (2009)
Diastolic blood pressure (mmHg)	≥ 85	Alberti et al. (2009)
Waist-height-ratio	> 0.5	Ashwell et al. (2012)
Glycosylated haemoglobin (%)	> 5.7*, ≥ 6.5% **	*CDC (2021), **Punthakee et al. (2018)
High-density lipoprotein (mmol/L)	1.0 in males, 1.3 in females	Alberti et al. (2009)
Low-density lipoprotein (mmol/L)	> 3.4	National Institute of Health (2001)
Heart rate variability (ms)†	< 30	(Mauss, Jarczok, et al., 2015)
Hair cortisol concentration (pg/mg)	N/A	N/A

Table 4. The physiological biomarkers measured to derive the ALI score, the standard threshold values, and sources. † Heart rate variability is calculated as the root mean square of successive differences (RMSSD)

ALI computation

The risk-quartile method (Juster et al., 2010) was adopted to transform the ALI into a summary score. The risk-quartile method was chosen due to its widespread use among researchers investigating work-related psychosocial stress in various occupational settings (Bellingrath et al., 2009; Schnorpfeil et al., 2003; J. Sun et al., 2007). Moreover, from its first application by Seeman et al. (1997), empirical evidence supports the robustness of the high-risk quartile index in determining an accurate representation of the state of allostasis and AL in the body (Sibille et al., 2017). This count-based method has also demonstrated the ability to capture several facets of general life and work-related stress and negative health outcomes, including cardiometabolic diseases and mortality risk (Seplaki et al., 2005)

To calculate the ALI, a measurement exceeding the threshold value, a score of "1" was assigned, while those measurements falling within the normal range were scored as "0". Higher scores indicate a high AL (or increased physiological strain).

4.4 Procedures on data collection days

On the day of data collection, participants met with team members between 8 am and noon. After being given a brief overview of the study and being able to ask questions, each firefighter provided informed consent (**appendix A**) to participate in the study. After consent was granted, an initial blood pressure assessment was conducted, and then a participant completed a set of 6 questionnaires (requiring about 20 minutes). Next, over a period lasting approximately 15-20 minutes, the various biomarkers forming the ALI were gathered (including a second blood pressure measurement).

Data were collected in a standardized fashion across participants:

1) Demographic Questionnaire: An in-house survey that included six questions relating to the general background characteristics of participants (e.g., age and gender); notably, individuals were asked to state the number of years that they have worked as a firefighter **(appendix C)**.

2) General Health Questionnaire: An in-house questionnaire that included 23 items relating to the health characteristics of the participants; some of the collected information was used to provide information that could enlighten the data analysis (e.g., impaired sleep patterns); **appendix D**. The questions were derived from the Canadian Community Health Survey (2016 version).

3) Multi-dimensional Scale of Perceived Social Support – Family and Partner (MS-PSS-FP): Adapted from Zimet et al.'s Multi-dimensional Scale of Perceived Social Support, the MS-PSS-FP contained eight questions to measure the degree of social support that participants felt they received from their significant other and/or immediate family members (e.g., there is a person available with whom joys and sorrows may be shared, or someone willing to help with decision-making); **appendix E**.

4) Social Support Scale for Firefighters (SSS-FF): Developed by Gulliver, the SSS-FF contained nine questions to measure the degree of social support that participants felt they

received from their co-workers (e.g., if there was a colleague available to provide advice, or a co-worker willing to lend money in a time of need); **appendix F**.

5) A Perceived Stress Scale (PSS): a widely used instrument with ten questions that measured the degree to which situations in a person's life are believed to be stressful (Cohen & Williamson, 1988); **appendix G**.

6) A Sources of Occupational Stress Questionnaire (SOOS - 14): a version of the original questionnaire (SOOS-57) created by Beaton & Murphy (1993), with 14 questions specifically curated to measure workplace psychosocial stress experienced by firefighters (Kimbrel et al., 2011); **appendix H**.

7) The Allostatic Load Index (ALI): The following physiological and anthropometric parameters were collected: scalp hair for cortisol assessment, HDL, LDL, HbA1c, SBP, DBP, WHtR, and HRV.

A detailed description of the procedure for data collection and each biomarker's collection technique, storage, and processing for the ALI are provided in **appendix I** and the methods section of chapters seven and eight.

4.5 Analytical Plan

Analyses performed in this thesis were a mixture of different statistical approaches to meet its varied objectives. In study 1, a literature review of the current literature was conducted to make a case for applying the AL model as a framework to investigate the cumulative consequences on the health and well-being of firefighters. For studies 2 and 3, the findings were reported using guidelines based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Page et al., 2021). Specifically, for study 3, the data extraction template from the Cochrane Consumers and Communication Review Group was used for data gathering. Study 4 was conducted using a cross-sectional study design to investigate associations between the psychosocial stress experience and AL within a sample of active firefighters while accounting for confounding and moderating factors. Statistical analyses included bivariate and linear regression modelling. Finally, for study 5, a longitudinal study design (2 time-points) was used to investigate the association between baseline psychosocial stress experience and AL change over time in a sample of active firefighters. Specific factors such as COVID-19-related stress and perceived social support were considered during the analysis. The linear mixed-effect model (Pinheiro & Bates, 2000) was used primarily for the statistical analysis. Moreover, due to the specificity of the statistical approach used for each project, a detailed description of each analytical approach is provided in each chapter's "statistical analysis" section.

Chapter 5

A SYSTEMATIC REVIEW OF HAIR CORTISOL IN HEALTHY ADULTS MEASURED USING IMMUNOASSAY METHODS: PROPOSED REFERENCE VALUES FOR RESEARCH AND METHODOLOGICAL CONSIDERATIONS[1]

5.1 Abstract

Hair cortisol concentration (HCC) has shown remarkable promise as a stable, non-invasive measure of systemic cortisol. However, the value typically seen in healthy adults has not been established despite methodological advances made. Therefore, we sought to review the relevant literature to determine a reference value for HCC in healthy (i.e., non-clinical) adults. To this end, we conducted a systematic review of the PubMed, Scopus, and CINAHL databases for studies that measured healthy adult HCC and focused on reports that used immunoassay methods, given that these are the most widely accessible analytical tools. In addition, studies were required to have been published in English, provided relevant descriptive statistics (e.g., means and standard deviations), and used a healthy human adult sample to be eligible.

We found 17 studies that met our inclusion criteria; the reports involved 1348 participants with a mean age of 35. After aggregating data from the various studies in a manner that accounted for differences in sample size, we estimated the mean HCC for healthy adults to be 60.51 pg/mg. Similarly, we also estimated the aggregated standard deviation as 90.38 pg/mg. Assuming that the mean plus two standard deviations are a reasonable border for extreme observations, a 241.28 pg/mg value could be used as an upper limit for HCC from a healthy adult population measured via immunoassay. Future work will need to determine whether our estimated reference value needs modification to account for potential moderating factors, such as age, sex, and ethnicity.

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[1] A version of this manuscript has been submitted to Psychophysiology for peer-review on July 28, 2022 (manuscript number PsyP-2022-0403).

5.2 Introduction

The steroid hormone cortisol is produced by specialised cells in the zona fasciculata of the adrenal gland cortex in response to activity within the hypothalamic-pituitary-adrenal axis, which is typically engaged in a wide variety of physiological processes (including inflammation and the stress response) (Godoy et al., 2018; Kyrou & Tsigos, 2009). Given the diversity of its biological roles, the assessment of cortisol has become an important tool in both clinical diagnosis (e.g., adrenal insufficiency, cardiometabolic disruption) and psychobiological investigation (e.g., behavioural stress research) (Lee et al., 2015; Levine et al., 2007). Indeed, in an effort to measure levels of cortisol over a short (acute) time, saliva, serum, and urine samples have all been used (Russell et al., 2012). However, along with capturing levels of the hormone within a narrow time window, assaying cortisol from the usual matrices often requires steps that make for an experimentally complex, or labour-intensive process (such as the need to collect multiple samples, or to use venipuncture) (Levine et al., 2007; Russell et al., 2012).

With the observation that various corticosteroids (cortisol and cortisone) are also deposited in human hair (Raul et al., 2004), scalp hair cortisol measurement has gradually emerged as an additional option for systemic cortisol measurement. The analysis of scalp hair has often been used to assess drug consumption and exposure to environmental toxins, so applying this matrix to stress hormone measurement has a solid technical foundation (Wester & Van Rossum, 2015). As well, since hair grows at a relatively constant rate (1 cm/month), separate segments can be prepared and assessed to allow the retrospective measurement of hair cortisol concentration (HCC) for periods ranging from a month to years (Grass et al., 2015; Stalder & Kirschbaum, 2012). Along with allowing for different hypotheses to be examined, hair cortisol measurement also has certain technical advantages over the more traditional methods. For example, scalp hair is not confounded by diurnal cortisol fluctuations (Stalder and Kirschbaum, 2012). As well, HCC provides the added advantage of overcoming many of the technical challenges associated with sampling serum, saliva, and urine: hair is easily collected and stored, lacks situational confounders (e.g., the stress of sampling procedure), and is unaffected by the cortisol-binding globulin as only free cortisol is measured (Russell et al., 2012; Stalder & Kirschbaum, 2012).

With the increasing recognition that scalp hair analysis can provide a means to determine retrospective systemic cortisol exposure, numerous studies have established the validity (Short et al., 2016; Thomson et al., 2010) and high test-retest reliability (Short et al., 2016; Stalder, Steudte, Miller, et al., 2012) of HCC assessment. In addition, various laboratories have integrated hair cortisol measurement into their study designs, which has led to the establishment of guidelines and standards for their collection and analysis (Gao et al., 2013; Russell et al., 2015; Sauvé et al., 2007; Wester & Van Rossum, 2015). Currently, two broad hair cortisol quantification processes are commonly used: gas/liquid chromatograph-mass spectrometry and immunoassays (Greff et al., 2019; Russell et al., 2015; Wester and Van Rossum, 2015). Gas and liquid chromatography-mass spectrometry (GC- and LC-MS) are highly sensitive and specific methods to determine HCC; however, they require expensive, specialised equipment, are time-consuming, need relatively large sample volumes, and have extended processing times (Gao et al., 2013). Further, a variety of immunoassay methods have also been used, including enzyme-linked immunosorbent assay (ELISA), (electro)chemiluminescence immunoassay (ECLIA/CLIA), luminescence immunoassay (LIA), radioimmunoassay (RIA), and enzyme immunoassay (EIA) (Russell et al., 2012, 2015). In addition, these immunoassay methods have consistently shown a highly positive intercorrelation (Chen et al., 2018; Russell et al., 2015). Notably, the growing popularity of immunoassay approaches has primarily been driven by their ability to offer an easy-to-use, high throughout, and low-cost alternative to spectrometry methods (Voegel et al., 2020).

Despite the recent progress made in HCC research and its growing acceptance by laboratories around the globe, a benchmark value, or range for HCC in healthy adults is lacking. The absence of a reference value may be partly attributable to the significant differences between the primary analytical methods (noted above) used to measure HCC. For example, according to Russell et al. (2015), immunoassays provide significantly greater levels of HCC when compared to mass spectrometry, ranging between 2.5- and 20-fold. A further complication may be that most published data using HCC has focused on establishing thresholds for pathological states, such as Cushing's disease, rather than understanding a healthy adult population.

Regardless of the reason, the absence of a reference range for healthy HCC in adults poses both a philosophical and practical barrier. Given the growing consensus that hair cortisol reflects a valid biometric to understand human physiology, knowing its typical level has significant epistemic value. On a more practical note, knowing the usual HCC that might be expected can aid in interpreting experimental results, or deciding whether a recorded value qualifies as "elevated". As a result, there is a pressing need to determine the range of hair cortisol values that would be seen in non-clinical cases. Since immunoassay analysis for HCC is the more technically accessible of the two most commonly used methods, and is the method of choice in a significant number of studies and laboratories (Russell et al., 2015; Stalder et al., 2010; Thomson et al., 2010), we decided to focus on data generated with this technique. Hence, our review aimed to answer the following research question, *"What is the benchmark value for scalp HCC in healthy adults measured using immunoassay methods?"*.

5.3 Materials and Methods

5.3.1 Search strategy and selection criteria

A systematic literature review was performed employing a strategy developed by all authors. First, using PRISMA guidelines (Moher et al., 2009), three primary databases (PubMed, Scopus, and CINAHL) were searched using relevant keywords, such as hair cortisol, healthy adults, corticosteroids, immunoassay, and reference value (a detailed description of the search strategies used is available in **appendix K**). Next, captured articles were downloaded into RefWorks (Legacy), a reference management software, where duplicated studies from all database searches were identified and removed. In addition, reference lists of captured articles were screened for additional studies not identified in the original search; notably, grey literature (such as government websites) was not included in our search strategy.

Before the literature search, a protocol outlining the eligibility criteria and extraction procedure was developed. For inclusion, articles were required to have (1) been published in the English language, (2) used an immunoassay method (CLIA, ECLIA, ELISA, RIA, LIA), (3) analysed a minimum scalp hair length of 1 cm, (4) reported non-transformed descriptive statistics of their point and range estimates [mean and standard deviation (SD), or confidence intervals (CIs)] and sample size, (5) involved human adult participants (>18 years of age), and (6) included a cohort, or control group that was deemed "healthy" by the authors based upon the exclusion of chronic physical and neuropsychiatric illnesses (e.g., diabetes, depression, and Cushing's disease).

Furthermore, excluded studies including those involving participants with characteristics that may be associated with altered cortisol levels: (a) certain physiological conditions (e.g., pregnancy, morbid obesity [group mean of subjects greater than 30 kg/m^2]), (b) medication, or substance use (e.g., steroid hormones, illicit drugs), and (c) traumatic/acute stress exposure. Systematic reviews, meta-analyses, conference proceedings, and editorials were also excluded. All reviewers agreed on studies meeting the eligibility criteria, and disagreements were settled in consultation with the senior author (JGM).

5.3.2 Data extraction and analysis

Our data extraction template was designed using the Cochrane Consumers and Communication Review group "data extraction template for Cochrane reviews" (Ryan et al., 2016). The following information was collected from the relevant reports: study design, sample size (number of male and female participants), average participant age, length of the hair sample, hair pulverisation method, immunoassay type, and mean HCC and standard deviation (SD).

Given the large variability in the reported means and standard deviations (**Figure 7**), the descriptive statistics were combined to estimate the mean and standard deviation of the aggregated population (*mixture distribution)* using the following formulae from finite mixture models (Fruhwirth-Schnatter, 2006):

$$Mean_{Agg.} = \frac{(n_1 * m_1 + n_2 * m_2 + ... + n_{14} * m_{14})}{n_1 + n_2 + ... + n_{14}}$$

$$SD_{Agg.} = \sqrt{\frac{n_1(SD_1^2 + m_1^2) + n_2(SD_2^2 + m_2^2) + \dots + n_{14}(SD_{14}^2 + m_{14}^2)}{n_1 + n_2 + ... + n_{14}} - (Mean_{Agg.})^2}$$

Where *m* is the sample mean, *n* is the study sample size, and *SD* is the study standard deviation for each of the 17 studies collected for the analysis.

For studies reporting only means and confidence intervals (CIs), the CI was converted to the SD using the following formula:

$$SD = \frac{\sqrt{n} * (Upper\ CI - Lower\ CI)}{(t_{\alpha,df} * 2)}$$

Where *n* is the study sample size, t_α is the t value, and *df* is the degrees of freedom.

For studies reporting means and standard error of the mean (SEM), the SEM was converted to SD using the following formula:

$$SD = SEM * \sqrt{n}$$

Where *n* is the study sample size, *SEM* is the standard error, and *SD* is the standard deviation.

Having determined the aggregate mean and SD, the following formula was used to arrive at potential reference values for high HCC within a healthy adult population:

elevated HCC reference value = aggregate mean + 1, 1.5, or 2 aggregate SDs

Where 1 SD represents a slight elevation, 1.5 SD is for moderate elevation, and 2 SD is for considerable elevation.

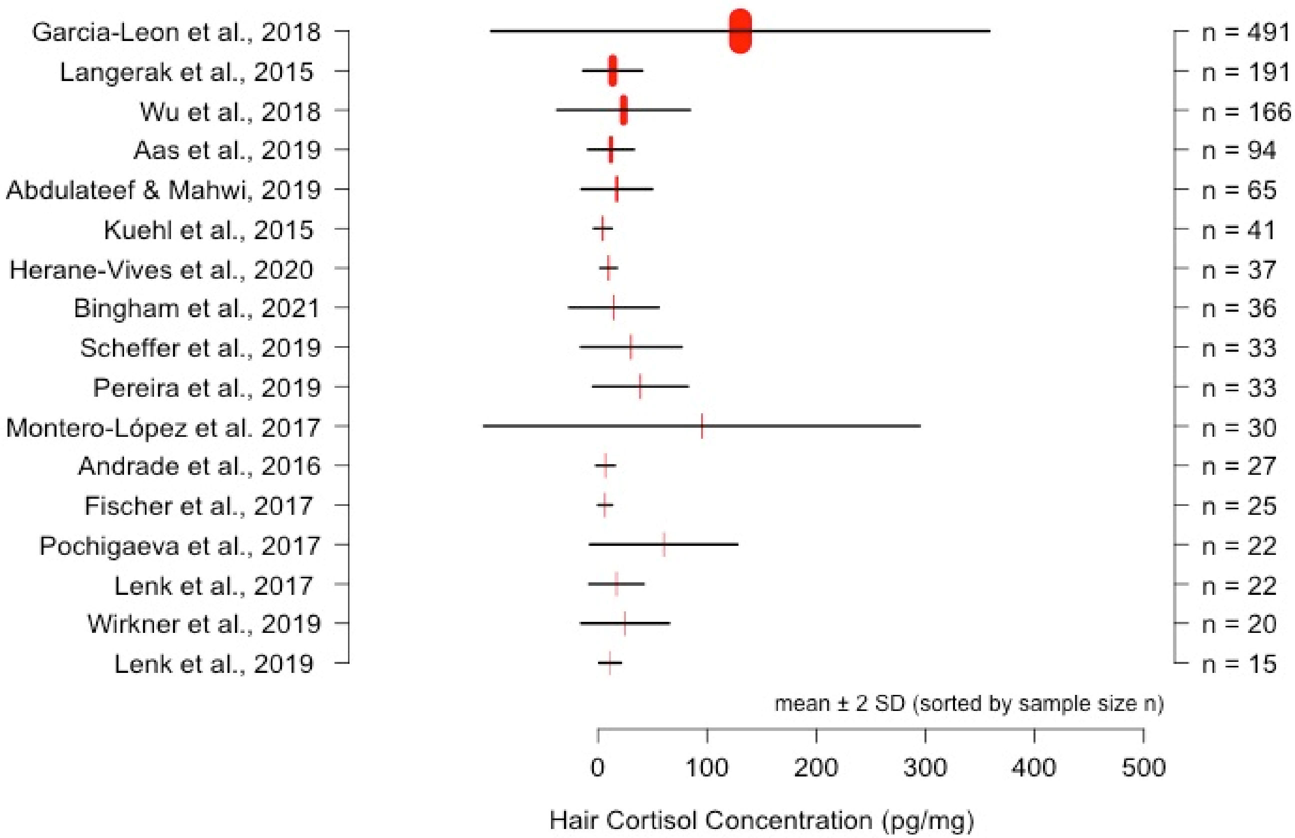

Figure 7: Variability within our dataset can be illustrated by examining the array of sample means ± 2 SDs. In the graph, the vertical lines represent the sample mean of each study with a thickness proportional to the sample size of that study. Quite clearly, the statistics reported by Garcia-Leon et al. (2018), with a sample size of n = 491, had a significant effect on our meta-analysis

5.4 Results

5.4.1 Search results

Appendix K outlines the flow chart used to select the studies that formed the basis of our review. The literature search returned 1011 studies (PubMed = 321, Scopus = 481, CINAHL = 195, other sources = 14), with 366 duplicates removed using RefWorks. After title and abstract screening, 225 studies underwent a full-text review, and 209 were excluded for reasons ranging from studies using non-healthy samples (85/208) to non-immunoassay methods (59/208). Further, three studies caught our attention, Cruickshank et al. (2021), Song et al. (2019), and Abdulateef and Mahwi (2019); despite meeting most of the inclusion criteria, they failed to report relevant details (e.g., HCC units compatible with our study) for our study. After contacting the authors, Abulateef and Mahwi (2019) provided the relevant data; however, up to the point of submission, we received no responses from the authors of the two other studies. Finally, 17 studies meeting our eligibility criteria entered the final data extraction and synthesis phase.

Error! Reference source not found. provides a summary of the design and demographic c haracteristics of the selected reports. Across the 17 studies, 1,348 participants were examined, with sample sizes ranging from 15 to 491 participants. Notably, one report (Garcia-Leon et al., 2018) involved 529 participants, but only 491 confirmed that they had not used drugs, and we chose to use this smaller sample for our analysis. As well, a total of 691 women and 556 men were recorded across fifteen studies; two reports (Abdulateef & Mahwi, 2019; Bingham et al.,

2021) did not provide a sex classification of their sample. In addition, the studies tended to include young to middle-aged participants, with the average age across the reports being 34.9 years (SD = 7.3 years). Finally, the participants were recruited from ten different countries, with the majority from Spain (521), followed by the Netherlands (191), the USA (166), Germany (123), Norway (94), Brazil (93), Iraq (65), Canada (36), Chile (31), and Russia (22).

5.4.2 Hair Collection and Preparation Information

Most studies reported that hair samples were retrieved from the posterior vertex of the scalp region with subsequent storage of the samples in aluminium foil at room temperature; a few studies reported that samples were kept for up to a year (2/17). According to a technical review by Meyer et al. (2014), processing hair samples for cortisol extraction includes the following procedures: preparation, washing, drying, grinding, extraction, evaporation, and reconstitution. Among our eligible studies, the regularly reported steps were sample preparation, washing, grinding, and the assay method. Regarding hair preparation, all seventeen studies reported the length of the hair sample collected: ten studies retrieved 3 cm of scalp hair, six studies used less than 3 cm, and one used 6 cm. Ball-milling was the method of choice for grinding the hair samples in most studies (9/17), followed by mincing with scissors (6/17). For washing, most studies reported washing samples twice with varying levels (1 mL – 5 mL) of isopropanol; notably, three studies (Abdulateef & Mahwi, 2019; Andrade et al., 2016; Bingham et al., 2021) did not report information on washing solvents. At the hair analysis stage, ELISA (8/17) and CLIA (6/17) were the most commonly used immunoassays, while EIA (1/17) and LIA (1/17) received limited use.

Author(s), Year of Publication	Study Design	Number of Men	Number of Women	Sample Age mean (SD)	Length (cm) of Hair Processed	Pulverisation Method	Immunoassay Method
Aas et al., 2019	case-control	42	52	35.3 (9.5)	3	ball milled	ELISA
Abdulateef & Mahwi, 2019	case-control	NR	NR	33.1 (10.4)	3	minced with scissors	CLIA
Andrade et al., 2016	case-control	11	16	26.4 (6.5)	2-3	ball milled	ELISA
Bingham et al., 2021	case-control	NR	NR	NR	3	ball milled	EIA
Fischer et al., 2017	case-control	25	0	25.8 (4.0)	2	minced with scissors	LIA
Garcia-Leon et al., 2018	cross-sectional	234	257	38 (16)	3	ball milled	ELISA
Herane-Vives et al., 2020	cross-sectional study	17	20	29.9 (1.4)	1	ball milled	ELISA
Kuehl et al., 2015	case-control	15	26	41.2 (2.6)	3	non-pulverised	CLIA
Langerak et al., 2015	case-control	88	103	36.4 (12.3)	3	minced with scissors	CLIA
Lenk et al., 2017	case-control	15	7	27.3 (10.0)	3	ball milled	CLIA
Lenk et al., 2019	case-control	11	4	32.5 (13.2)	3	ball milled	CLIA

Author(s), Year of Publication	Study Design	Number of Men	Number of Women	Sample Age mean (SD)	Length (cm) of Hair Processed	Pulverisation Method	Immunoassay Method
Montero-López et al., 2017	case-control	0	30	44.7 (11.7)	3	ball milled	ELISA
Pereira et al., 2019	case-control	3	30	38.0 (9.7)	1	minced with scissors	ELISA
Pochigaeva et al., 2017	case-control	0	22	42.6 (12.8)	1	minced with scissors	CLIA
Scheffer et al., 2019	case-control	3	30	40.9 (11.5)	1	minced with scissors	ELISA
Wirkner et al., 2019	cross-sectional	0	20	21.1 (2.5)	6	NR	IA
Wu et al., 2019	cross-sectional	92	74	45.7 (9.8)	1	ball milled	EIA

Table 5. Design and demographic characteristics of studies that form the dataset for the systematic review and meta-analysis. CLIA, Chemiluminescence immunoassay; EIA, enzyme immunoassay; ELISA, enzyme-linked immunosorbent assay; IA, immunoassay; LIA luminescence immunoassay; NR, not reported; SD, standard deviation

5.4.3 Other factors considered

Certain factors are considered relevant to HCC analysis (Stalder & Kirschbaum, 2012) and were frequently mentioned in the eligible studies. The commonly acknowledged factors were demographic variables like education and employment status, followed by body composition variables (e.g., waist circumference, weight, body mass index), behavioural habits such as tobacco and alcohol consumption, use of contraceptives, and hair-care (e.g., hair wash frequency, dying, perming, and bleaching). However, among studies that considered these factors as covariates analysing HCC, none reported any significant impact on the reported HCC in healthy adults.

5.4.4 HCC reference value for research in healthy adults

Although most eligible studies similarly reported their data, three reports displayed methodological variability that required additional analysis before their data could be incorporated into our review. Typically, the eligible studies reported HCC in picograms/milligrams (pg/mg) and reported both raw means and SDs. Some eligible studies also provided log-transformed means and median/interquartile ranges (IQR); however, only the raw means and SDs were recorded and considered for our analysis. A few studies stood out; both Lenk et al. (Lenk et al., 2017, 2019) studies provided HCC means and CIs, which we converted to SDs. Further, the Kuehl et al. (2015) study provided HCC means and SEMs for men and women separately, while Pereira et al. (2019) provided the HCC mean and SEM for their sample; as a result, we converted the SEMs to SDs.

Table 6 and **Figure 7** summarise the eligible studies' sample sizes, means, and SDs. Based on our analysis, the HCC aggregate mean for the 14 eligible studies was 60.51 pg/mg, while the aggregate SD was 90.38 pg/mg. As a result, reference values for elevated HCC within a healthy adult population measured via immunoassay could be reasonably estimated in the following fashion: (a) the mean plus 1 SD (150.90 pg/mg) could be considered as a slight elevation, (b) the mean plus 1.5 SDs (196.09 pg/mg) could be regarded as a moderate elevation, and (c) the mean plus 2 SDs (241.28 pg/mg) could be described as a considerable elevation.

Author(s), Year of Publication	**Total Sample Size**	**Mean HCC**	**Weighted Mean HCC**	**SD**	**Variance**
Aas et al., 2019	94	11.77	1106.38	10.50	110.25
Andrade et al., 2016	27	6.82	184.03	4.35	18.91
Abdulateef & Mahwi, 2019	65	17.22	119.3	16.23	263.41
Bingham et al., 2021	36	14.56	524.16	20.43	417.38
Fischer et al., 2017	25	6.32	158.00	3.25	10.56
Garcia-Leon et al., 2018	491	130.30	63975.19	114.04	13005.12
Herane-Vives et al., 2020	37	9.7	358.90	3.8	14.44
Kuehl et al., 2015	41	4.32	177.30	4.07	16.55
Langerak et al., 2015	191	13.50	2578.50	13.50	182.25
Lenk et al., 2017	22	16.98	373.56	12.56	157.82
Lenk et al., 2019	15	11.06	165.90	5.05	25.47
Montero-López et al., 2017	30	95.18	2855.46	99.74	9948.67
Pereira et al., 2019	33	38.91	1284.03	21.71	471.32
Pochigaeva et al., 2017	22	60.20	1324.40	33.80	1142.44
Scheffer et al., 2019	33	30.36	1001.88	23.11	534.07
Wirkner et al., 2019	20	24.83	496.60	20.20	408.04
Wu et al., 2019	166	23.43	3889.38	30.47	928.42

Table 6. Sample size and descriptive statistics of studies that form the dataset for our systematic review and meta-analysis. HCC, hair cortisol concentration; SD, standard deviation

5.5 Discussion

The present study aimed to review existing research on HCC to establish a reference value that may be used for psychobiological research with healthy adults. To this end, we collected data from studies that used immunoassay methods to measure the cortisol concentration in hair samples collected from healthy participants. Our findings indicate that an average value for HCC in healthy adults is 60.51 pg/mg, and that 150.90 pg/mg (which represents the aggregate mean + 1 SD) could be considered a reasonable threshold at which to begin considering an HCC value as being elevated. Further, researchers may select a more stringent threshold based on various considerations using the aggregate mean plus 1.5 or 2 SDs.

To the best of our knowledge, this study represents the first attempt to provide a benchmark value for HCC in healthy adults measured using immunoassay methods. Although we believe that our search methodology has allowed us to establish a reasonable HCC estimate, certain sources of variability need to be considered (and should inform the use of the estimate); in particular, age and sex may exert an influence on HCC (Dettenborn et al., 2012; Wosu et al., 2015). With regards to age, evidence exists to support a positive linear association between age and HCC (Dettenborn et al., 2012; Feller et al., 2014; Stalder et al., 2013), although there are studies that have shown a non-significant association between both variables (Manenschijn et al., 2011; Raul et al., 2004).

Similarly, inconsistent findings have been observed in the case of sex and HCC; for example, some authors have observed a higher HCC in adult men compared to women (Dettenborn et al., 2012; Feller et al., 2014; Manenschijn et al., 2013), while no sex difference has been found in other studies (Manenschijn et al., 2011; Raul et al., 2004; Stalder, Steudte, Alexander, et al., 2012; Thomson et al., 2010). Among the studies captured for our report, only two (Garcia-Leon et al., 2018; Kuehl et al., 2015) stated HCC means stratified based on sex. For Garcia-Leon et al. (2018), men reported a lower HCC mean (125.52 pg/mg, SD = 112.85 pg/mg) compared to women (134.64 pg/mg, SD = 115.16 pg/mg). In contrast, Kuehl et al. (2015) reported a higher HCC in men (6.1 pg/mg, SD = 1.4 pg/mg) than that found in women (3.3 pg/mg, SD = 0.6 pg/mg). Importantly, neither report found that the difference in HCC values between male and female adults reached the threshold for statistical significance.

Although age and sex are important factors when imagining the shape of normative HCC values, ethnicity should also be considered. For example, Black Americans have been found to have median HCC levels about 15% higher than those observed among Hispanic Americans and about 60% higher than White Americans (Wosu et al., 2015). In addition, the texture of hair can vary across ethnic groups and may be a source of variation in both collection and analysis (Wright et al., 2018). As a result, we were quite surprised when we observed that the majority of the studies that we collected did not provide information on the ethnic background of their participants, and that those reporting this information did not relate participant ethnicity to HCC values.

Along with demographic factors, the effect that the segmental analysis of hair samples may have on HCC cortisol has also been highlighted in previous research. For instance, evidence suggests that HCC decreases along the hair sample as one moves distally from the scalp (Dettenborn et al., 2012; Wosu et al., 2013). The finding has been attributed to the "wash out" effect (gradual decline in cortisol content in hair over time) occurring due to exposure to elements like water, heat, and sunlight (Dettenborn et al., 2010). In contrast, Manenschijn et al. (2011) study found no significant difference between consecutive hair segments (i.e., each segment = 3 cm of hair sample). As well, the pulverisation method used to increase the surface area of the hair sample may also influence the measurement, given two studies that provide evidence of elevated HCC obtained from ball-milled (powder form) hair samples (Davenport et al., 2006; Eser et al., 1997). Eser et al. (1997) notably revealed a 3.5-times greater HCC yield from ball-milled powdered hair samples than samples finely minced with scissors.

Other situational and behavioural factors that should be considered during HCC measurement include hair washing and cosmetic treatment (Dettenborn et al., 2012; S. K. Kristensen et al., 2017; Wosu et al., 2015), smoking (Dettenborn et al., 2012; Goldberg et al., 2014), oral contraceptive use (Dettenborn et al., 2012; Garcia-Leon et al., 2018; Stalder et al., 2017), sweat (Russell et al., 2014), and sunlight exposure (Grass et al., 2016; Wester et al., 2016). Despite the mixed findings (i.e., positive, negative, or insignificant associations) regarding the potential influence that the noted demographic, technical, and behavioural factors may have upon HCC, we believe that they should be considered when considering the application of the reference value we have estimated.

With reference to our systematic review methodology, a few considerations should be noted. First, since we included only published studies, our findings may be subject to a publication bias. Further, our review of only English studies introduces a language bias and the possibility that we may have overlooked relevant data. In addition, studies with participants experiencing ongoing acute/traumatic stress, for example, living in conflict/war (Etwel et al., 2014), were deemed ineligible. Nevertheless, we acknowledge that the "healthy" participants in the studies we summarised may have experienced varying degrees of stress (e.g., daily hassles, work-related stressors) that may not have been measured or taken under consideration. As well, the descriptive statistics used in our calculation of the aggregate mean and standard deviation may not have come from samples that were normally distributed; indeed, a majority of the studies indicated that their samples were skewed and required transformation prior to statistical analysis.

Finally, there were several potentially relevant reports that we were unable to include in our analysis, given that the authors reported their summary data in forms that we were not able to use, such as medians, geometric means, and ranges, which resulted in the loss of potentially valuable information. In light of these limitations, our findings should be considered cautiously.

5.6 Conclusion

The absence of a reference value for HCC in healthy adults has been one obstacle in the adoption of hair cortisol as the "gold standard" for systemic cortisol measurement (Russell et al., 2015; Staufenbiel et al., 2013). To address this problem and further advance the field, our review attempts to provide a benchmark value for healthy adult HCC measured using immunoassay methods. Indeed, with the establishment of a normative benchmark for HCC in healthy adults, clinicians and researchers will have a tool to help distinguish pathological states from non-clinical samples. Of course, our efforts to arrive at a reference value have led us to recognise that such a value represents only a first step; that is, future research needs to be done to allow our aggregate estimate to become more accurate and precise. In particular, the research community needs to sort out the influence of potentially important moderating factors, such as age, sex, ethnicity, and basal perceived stress level, to determine whether the value we are proposing is reasonable, or needs to become more nuanced.

Chapter 6

HEALTH OUTCOMES OF PSYCHOSOCIAL STRESS WITHIN FIREFIGHTERS: A SYSTEMATIC REVIEW OF THE RESEARCH LANDSCAPE[2]

6.1 Abstract

Background and Objectives: Much of the research surrounding firefighter health has concerned the hazards intuitively associated with the occupation, such as physical, thermal, and chemical risks. However, an additional aspect of their work environment, psychosocial stressors, has begun to attract a growing level of attention.

Work-related psychosocial stress may best be described as mental and emotional strain caused by a combination of workplace events and characteristics, and the objective of our review was to identify the health outcomes associated with these stressors in firefighters.

Methods: A systematic review was performed of studies reporting on the psychosocial stressors and the associated health outcomes experienced by firefighters. Data sources included the MEDLINE, PsychInfo, and CINAHL databases.

Results: Twenty-nine studies met the inclusion criteria. Upon analysis, we found that firefighters experienced a range of psychosocial stressors (including interpersonal conflict and concerns over organizational fairness) and observed that these stressors were associated with a number of health-related outcomes that could be arranged into six areas: depression-suicidality, non-depressive mental health problems, burnout, alcohol use disorders, sleep quality, and physiological parameters and somatic disorders.

Conclusion: Our findings strongly suggest that work-related psychosocial stressors can affect the health and well-being of those in the fire service, and highlight that interventions meant to address these psychosocial risk factors should focus upon promoting self-esteem, enhancing self-efficacy, and strengthening social support.

KEYWORDS firefighter, first responder, health and well-being, mental health, psychosocial stress

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[2] This study was published in the Journal of Occupational Health. Citation: Igboanugo, S., Bigelow, P. L., & Mielke, J. G. (2021). Health outcomes of psychosocial stress within firefighters: A systematic review of the research landscape. *Journal of occupational health*, *63*(1), e12219. Permission to use published copy is available on page 256.

6.2 Introduction

Although certain factors are common across nearly all occupations, there can be little doubt that some occupational groups are comparatively unique. One of the best examples of such a group is public safety personnel, whose members undertake work that may routinely present significant emotional, psychological, and physical challenges. Indeed, one of these groups, the fire service, engages in a wide range of tasks that serve to clearly set them apart. For example, in many jurisdictions, firefighting has progressed from the already significant responsibilities related to fire prevention and suppression to also include rescue operations, hazardous material response, and the provision of emergency medical services (DeJoy et al., 2017; Vock, 2018). As well, changes in a variety of contextual factors, such as residential fire dynamics, the growth of wildland-urban interfaces, and demographic shifts, have further complicated work within the fire service (Comeau, 2009; Kerber, 2012; Radeloff et al., 2018).

As might be expected, given their essential role in emergency preparedness, the occupational environment of firefighters has been the focus of much research, and this effort has helped to establish that their working conditions are linked to a variety of health concerns (Guidotti & Clough, 1992; Jahnke et al., 2012; Melius, 2001). Over the past few decades, much of the research investigating firefighter health has concerned the sort of hazards that would intuitively be associated with the occupation, such as physical, thermal, ergonomic, and chemical risks. In addition, attention has been directed at the effects of traumatic/critical incidents (W. Berger et al., 2012; E. C. Meyer et al., 2012). However, an additional aspect of their environment – psychosocial workplace stressors – has begun to attract a growing level of attention.

Job-related psychosocial stress may best be described as a combination of work events and characteristics that affect individuals by applying mental and emotional strain, and has become the subject of heightened interest given evidence that these factors can negatively affect the health of an individual, regardless of company size, area of expertise, or their position within the company (Ganster & Rosen, 2013). For example, a meta-analytical review investigating psychosocial stress in the work environment and mental health outcomes supported the notion that exposure to such stressors prospectively increased the risk of common mental health disorders (Stanfeld & Candy, 2006). As well, a subsequent systematic review also found strong evidence for an association of work-related, psychosocial stressors with the incidence of various stress-related disorders (Nieuwenhuijsen et al., 2010). In addition, ongoing exposure to psychosocial stressors can lead to fatigue, burnout, and a variety of chronic diseases within a workforce (Ganster & Rosen, 2013; Quick & Henderson, 2016). Similarly, a number of health-related behaviours associated with chronic disease development (e.g., smoking, alcohol abuse, and physical inactivity) have been linked with exposure to psychosocial stressors (Griep et al., 2015; Rutters et al., 2014; Siegrist & Rödel, 2006).

Since research into the influence of psychosocial stressors experienced by firefighters has steadily grown, there is a need to identify and synthesise the evidence highlighting the effect of these stressors on the general health of this occupational group. Therefore, the objective of our review was to investigate the academic literature to answer the following key research question: *what health outcomes are associated with the work-related psychosocial stressors typically experienced by those within the fire service?*

6.3 Methods

6.3.1 Search Strategy and Selection Criteria

A review of the literature was carried out by two of the researchers (SI and JM) employing a strategy developed by all of the authors. Those databases thought to possess the most relevant journals were searched (Medline, CINAHL, and PsychINFO) using MeSH terms and author keywords, such as *stress, psychosocial stress, firefighters, burnout, emotional disorders,* and *chronic disorders/illness* (a detailed description of the search strategies can be found in **Appendix L**). Prior to beginning the search, a protocol outlining both the eligibility criteria and extraction procedure was developed. For inclusion, articles were required to have (1) been published in the English language, (2) involved a general sampling of firefighters (as opposed to including only participants with a particular experience, such as traumatic exposure) (3) measured psychosocial stress, (4) assessed at least one health-related outcome, and (5) applied an analytical method to directly examine the nature of the association between psychosocial stress and a health-related outcome.

Although many studies investigated different stressors pertaining to firefighters (such as toxicant exposure), we focused on those that specifically investigated some element of psychosocial stress. Since effects upon firefighter health and well-being were the outcome of interest for our review, any article measuring physiological, pathological, psychological, or behavioural changes was captured for further assessment. Notably, previous systematic reviews, conference proceedings, and editorials were excluded. Duplicates were identified and removed using a RefWorks database. Articles meeting eligibility criteria underwent full-text review, and their accompanying reference lists were perused for additional articles not identified in the original search.

6.3.2 Data Extraction and Analysis

The Cochrane Consumers and Communication Review Group data extraction template guided the development of our data extraction procedure (Ryan, 2013); information was collected on study location and design, sample characteristics, tools used for psychosocial stress measurement, health outcomes examined, and the primary findings (which were summarised in both a qualitative and quantitative manner). To assist in the evaluation of the assembled reports, we assigned a design and reporting score (DRS) to each one based upon whether the study included 8 items that we felt were important elements: a statement that the study had undergone review by an ethics committee, a statement that informed consent had been sought, a description of participant characteristics (at a minimum, age and gender), a description of the psychometric properties of the stress measurement tool (that is, Cronbach's alpha), an informative description of the health outcome measurement tool (typically, a meaningful summary of the tool together with at least one relevant citation), the provision of descriptive statistics for the measurement tools (minimally, the mean and standard deviation of scores, or values for at least one of the instruments used), a comment regarding whether the assumptions underlying the analytical tools were considered (e.g., normality, or collinearity), and consideration regarding potential study limitations. Notably, the 29 reports tended to display most of the items on our checklist (average DRS = 5.8, standard deviation = 1.4). Two reviewers (SI and JM) independently examined each study and settled any disagreements related to data extraction through discussion leading to consensus.

6.4 Results

6.4.1 Study and Sample Characteristics

Our initial literature search returned 1415 articles, which were then screened for eligibility (a description of the identification and screening process may be found in **Appendix M**). After removing duplicates, we reviewed titles and abstracts and eliminated those reports not fitting our inclusion criteria, which left 112 studies. After a full-text review and evaluation of associated reference lists (to identify relevant articles that may not have been captured in our database search), we settled on 29 studies investigating psychosocial stress and its association with some aspect of firefighter health.

During the analysis, a noticeable degree of methodological heterogeneity was observed across the eligible articles. For example, significant variation was found in the measurement tools used for the evaluation of psychosocial stress; in particular, 15 different scales were used, with the most common one (the Korean Occupational Stress Scale) appearing in 6 studies, and most appearing in only a single report. In addition, 18 separate health-related signs, symptoms, or disorders were assessed, with similar ones often examined using more than one tool; for instance, the 4 studies focused on excessive alcohol use employed 3 different scales. As a result, the extracted data were not considered appropriate for a meta-analysis; instead, we chose to arrange the reports according to 6 themes (each of which were discussed in at least 3 reports): depression-suicidality, non-depressive mental health problems, burnout, alcohol use disorders, sleep quality, and physiological parameters and somatic disorders (**Tables 7 - 12**). Notably, some reports assessed more than a single health outcome, and were therefore placed under more than one theme.

Most of the studies used a cross-sectional design (27/29), with only two using a longitudinal design (An et al., 2015; Ângelo & Chambel, 2013). A clear majority of the reports focused upon firefighters within either Asia (15/29; particularly, South Korea), or the United States (8/29), with the remaining studies drawn from South American (1/29) and European (5/29) populations. The total number of participants investigated across the studies was 89,262 with sample sizes ranging from 186 to 45,698 (median = 651). Overall, 15 studies examined both male and female firefighters, 12 reports focused solely on male firefighters, 1 study involved just female firefighters (Jahnke et al., 2019) , and 1 report considered male, female and transgender firefighters (Stanley et al., 2018).

6.4.2 Psychosocial stressors and depression-suicidality

We identified eight studies that examined whether an association was present between psychosocial stressors and depression-suicidality in firefighters (**Table 7**). Most of the selected reports focused upon depression, and they consistently observed that work-related psychosocial stress could influence the likelihood that a firefighter would experience depressive symptoms. For example, An et al. (2015) one of the two longitudinal studies that we encountered, observed that a high-level of stress rooted in a firefighter's organizational system caused a marked increase in their risk for depression (OR 8.03; 95% CI: 1.73, 37.22); within the study, organizational system stress was largely related to how employees viewed their organization's fairness, the level of organizational support they received, and whether they believed their position and progress were appropriate relative to their abilities. In addition, we found three cross-sectional reports (Saijo et al., 2007, 2008; Stanley et al., 2018) that made use of the Center for Epidemiologic Study Depression Scale, and each one observed a positive relationship between occupational stress and depressive symptoms; notably, the two reports from Saijo et al. (2007, 2008) found a high variance in workload and high intergroup conflict were among the most important factors influencing the association between occupational stress and depressed mood.

Similarly, another report that used a different measure of work-related well-being found that relationship conflicts were a significant variable underlying depressed mood (Payne & Kinman, 2019). The final depression-related study that we located was unique among all of the work that we reviewed, in that the investigators focused just on female firefighters (Jahnke et al., 2019). The authors noted that the risk of depressive symptoms increased with the level of perceived work-related discrimination, and the risk profile was clearest among those experiencing the greatest levels of harassment (OR 4.20; 95% CI: 3.25, 5.67).

Two of the reports that addressed the relationship between occupational stress and suicidality in firefighters used the revised Suicide Behaviors Questionnaire (SBQ-R) (Osman et al., 2001), whereas the remaining study used the suicidal ideation item from the Beck Depression Inventory. With a sample of nearly a thousand participants, the first report (Stanley et al., 2018) found that scores on the Sources of Occupational Stress Scale (which captures many of the psychological stressors inherent in firefighting; Kimbrel et al., 2011) were able to significantly predict each of the four items assessed by the SBQ-R (indicating a relationship with not only the lifetime prevalence and frequency of suicidal ideation, but also the relative likelihood of suicidal behavior). The second report employed a large nationwide survey of Korean firefighters to determine that occupational stress caused by difficulties in the physical work environment increased the risk for suicidal ideation over the past year (OR 1.19; 95% CI: 1.16, 1.22); notably, the authors chose to measure only this element of the SBQ-R (H. Park et al., 2019). The final study also found a clear association between occupational stressors and suicidal ideation, but observed that this relationship was only apparent amongst those firefighters who reported having a low level of social support (Carpenter et al., 2015).

Author, Year of Publication (DRS)	**Study Location**	**Study Design**	**Sample Size**	**Psychosocial Stress Measurement Tool**	**Health Outcome; Measurement Tool**	**Core Results:** *narrative*	**Core Results:** *quantitative*
An et al., 2015 (4/8)	Seoul, South Korea	longitudinal (panel design with two waves of data collection)	186 men	Korean Occupational Stress Scale, short form	depression; Korean version of the Beck Depression Inventory	Risk of depression was inversely related to how positively a firefighter viewed their organisational system.	OR (adjusted for age, job class, and shift work) for depression with high organisational system stress (including 95% CIs): 8.03; 1.73, 37.22
Carpenter et al., 2015 (7/8)	USA (various urban settings)	cross-sectional	299 men 35 women	Sources of Occupational Stress scale, short form	suicidal ideation; ideation item from either the Beck Depression Inventory – II, or from the Beck Depression Inventory for Primary Care	Suicidal ideation was more prevalent amongst those reporting higher levels of occupational stress.	individuals with above median levels of occupational stress reported having at least 1 episode of suicidal ideation [$\chi^2(1) = 5.10$, Fisher's exact $p = .035$]

Jahnke et al., 2019 (8/8)	USA and Canada	cross-sectional	1773 women (~98% from USA)	Chronic Work Discrimination and Harassment, abbreviated scale	depression; Center for Epidemiologic Studies – short depression scale	The risk of depression increased with the level of perceived discrimination and harassment.	those with the highest level of perceived discrimination and harassment had an elevated risk of depressive symptoms (OR = 4.20; 95% CI = 3.25, 5.67)
Park et al., 2019 (5/8)	South Korea	cross-sectional	42326 men 3372 women	Korean Occupational Stress Scale, difficult physical environment sub-scale	suicidal ideation; Suicidal Behaviors Questionnaire, revised	Occupational stress from the physical work environment influenced an increase in suicidal ideation.	high occupational stress increased risk for suicidal ideation in the past year (OR = 1.19; 95% CI = 1.16, 1.22)
Payne & Kinman, 2019 (7/8)	United Kingdom	cross-sectional	773 men 136 women	Health and Safety Executive Management Standards Tool	work-related anxiety and depression; Warr's scale of job-related affective well-being, modified version	Job demands and job resources significantly contributed to work-related depression.	relationship conflicts ($\beta = 0.17$, $p < .001$) and a sense of control ($\beta = 0.09$, $p < .01$) were significantly associated with work-related depression

Saijo et al., 2007 (5/8)	Hokkaido, Japan	cross-sectional	1626 men 46 women (same data set used in Saijo et al., 2008)	National Institute for Occupational Safety and Health generic job stress questionnaire, Japanese version	depression; Center for Epidemiologic Studies – depression scale	High variance in workload, high intergroup conflict, high role conflict, and low self-esteem significantly increased risk for depressive symptoms.	high variance in workload (OR; 95% CIs): 2.05; 1.29, 3.25 high intergroup conflict: 1.91; 1.26, 2.88 high role conflict: 1.87; 1.24, 2.80 low self-esteem: 5.78; 3.93, 8.50
Saijo et al., 2008 (6/8)	Hokkaido, Japan	cross-sectional	1209 men 92 women (same data set used in Saijo et al., 2007)	National Institute for Occupational Safety and Health generic job stress questionnaire, Japanese version	depression; Center for Epidemiologic Studies – depression scale	High variance in workload, high intergroup conflict, high role ambiguity, and low self-esteem significantly increased risk for depressive symptoms.	high variance in workload (OR; 95% CIs): 2.08; 1.22, 3.56 high intergroup conflict: 1.70; 1.02, 2.85 high role ambiguity: 1.63; 1.04, 2.56 low self-esteem: 5.16; 3.32, 8.01

Stanley et al., 2018 (8/8)	southern USA (urban setting)	cross-sectional	785 men 40 women 6 transgender	Sources of Occupational Stress scale, short form	depression; Center for Epidemiologic Study – depression scale	Occupational stress and depressive symptoms showed a linear relationship.	occupational stress was significantly correlated with depressive symptoms ($r = .48$, $p < .01$)
Stanley et al., 2018 (8/8)	southern USA (urban setting)	cross-sectional	785 men 40 women 6 transgender	Sources of Occupational Stress scale, short form	suicidal ideation; Suicidal Behaviors Questionnaire, revised	Increasing occupational stress predicted greater levels of suicidal ideation and behaviour.	lifetime suicidal ideation ($\beta = 0.013$, $p < .001$), past year suicidal ideation ($\beta = 0.006$, $p < .005$), lifetime suicide threats ($\beta = 0.003$, $p < .003$), and current suicidal intent ($\beta = 0.008$, $p < .003$) were significantly associated with work-related stress

Table 7. Characteristics and key findings from studies examining the relationship between psychosocial stressors and depression-suicidality in firefighters. BDI, Beck Depression Inventory; CI, confidence interval; DRS, design and reporting score; OR, odds ratio; SOOS, sources of occupational stress

6.4.3 Psychosocial stressors and non-depressive mental health problems

We located five studies that considered whether non-depressive mental health problems (primarily, those related to anxiety) in firefighters might be associated with work-related stress (**Table 8**). The largest study we captured, which focused exclusively upon female participants, observed that workplace discrimination and harassment clearly increased the frequency and severity of current anxiety symptoms (Jahnke et al., 2019). In a similar fashion, relationship conflicts were also found to increase the likelihood of work-related anxiety amongst a mixed sample of male and female firefighters (Payne & Kinman, 2019). In taking a comparatively broader view of psychosocial stressors in the work environment, Teoh et al. (2019) found that a firefighters' perceptions of their workplace demand and their perceived level of influence significantly predicted psychiatric morbidity (a measure encompassing symptoms of common mental health disorders, including anxiety).

Post-traumatic stress disorder (PTSD) has gained increasing attention as a problem facing public safety personnel (W. Berger et al., 2012; Haugen et al., 2012). Of the three PTSD-related reports that we found, two were focused upon male and female Japanese firefighters, and observed that greater levels of perceived job stress were associated with a greater probability of self-reported post-traumatic symptoms (Mitani et al., 2006; Saijo et al., 2012); as well, among those experiencing symptoms, inter-group conflict and low levels of supervisor support were found to be important moderating variables. The third report concerned American female firefighters, and found that those experiencing the highest level of discrimination were more than twice as likely to report symptoms reflective of PTSD (Jahnke et al., 2019).

Author, Year of Publication (DRS)	**Study Location**	**Study Design**	**Sample Size**	**Psychosocial Stress Measurement Tool**	**Health Outcome; Measurement Tool**	**Core Results:** *narrative*	**Core Results:** *quantitative*
Jahnke et al., 2019 (8/8)	USA and Canada	cross-sectional	1773 women (~98% from USA)	Chronic Work Discrimination and Harassment, abbreviated scale	anxiety; Mental Health Inventory, anxiety sub-scale	More symptoms of anxiety over the past month were observed in firefighters with the highest level of perceived discrimination and harassment.	those in the highest tertile of perceived discrimination and harassment reported approximately 30% more symptoms of anxiety than those in the lowest tertile ($p < .001$)
Jahnke et al., 2019 (8/8)	USA and Canada	cross-sectional	1773 women (~98% from USA)	Chronic Work Discrimination and Harassment, abbreviated scale	PTSD; Trauma Screening Questionnaire	The risk of PTSD-related symptoms increased with the level of perceived discrimination and harassment.	those with the highest level of perceived discrimination and harassment had an elevated risk of PTSD symptoms (OR = 2.67; 95% CI = 1.82, 3.93)

Mitani et al., 2006 (4/8)	Japan (1 rural fire service, 1 urban fire service)	cross-sectional	237 men 4 women	Japan Brief Job Stress Questionnaire	PTSD; revised Impact Event Scale, Japanese version	A greater amount of perceived job stress was associated with a greater frequency of self-reported post-traumatic symptoms.	job stress was significantly correlated with PTSD symptoms ($r = .37$, $p < .01$)
Payne & Kinman, 2019 (7/8)	United Kingdom	cross-sectional	773 men 136 women	Health and Safety Executive Management Standards Tool	work-related anxiety and depression; Warr's scale of job-related affective well-being, modified version	Job demands and job resources significantly contributed to work-related anxiety.	relationship conflicts ($\beta = 0.12$, $p < .01$) and role clarity ($\beta = 0.08$, $p < .05$) were significantly related to work anxiety
Saijo et al., 2012 (6/12)	Hokkaido, Japan	cross-sectional	1621 men 46 women	National Institute for Occupational Safety and Health generic job stress questionnaire, Japanese version	PTSD; Impact of Event scale – revised, Japanese version	After adjustment for age and gender, the PTSD-positive group endorsed significantly higher inter-group conflict and role ambiguity, and lower social support from supervisors.	When comparing high vs low PTSD groups: high role ambiguity: Cohen's $d = 0.27$, $p = .002$ low social support from supervisor: Cohen's $d = 0.22$, $p = .19$

Teoh et al., 2019 (7/8)	Minas Gerais, Brazil	cross-sectional	276 men 36 women	Job Stress Scale, Portuguese version	psychiatric morbidity; self-report questionnaire	Increased job demands lead to greater psychiatric morbidity, while improved job control had a beneficial effect.	job demands (β = 0.12, $p < .05$) and job control (β = -0.30, $p < .001$) were significant predictors of psychiatric morbidity

Table 8. Characteristics and key findings from studies examining the relationship between psychosocial stressors and non-depressive mental health problems in firefighters. CI, confidence interval; DRS, design and reporting score; OR, odds ratio; PTSD, post-traumatic stress disorder.

6.4.4 Psychosocial stressors and burnout

Burnout is typically regarded as a psychological response to chronic occupational stress, and tends to be characterized by emotional exhaustion, disengagement, and a reduced feeling of job-related efficacy (Maslach et al., 2001). We captured five reports that focused upon determining whether work-related stressors might be antecedents to burnout among firefighters (**Table 9**). The first of these reports used a cross-lagged panel analysis to measure reciprocal relationships between organizational demands and burnout in a large sample of Portuguese firefighters (Ângelo & Chambel, 2013). Interestingly, the authors observed that the perception of increased organizational demands by their participants predicted the likelihood of burnout, which, in turn, was associated with an altered perception of job demands. With a focus on several hundred male and female firefighters, two cross-sectional studies also found that job stressors and strains were positively associated with burnout (Mitani et al., 2006; Smith et al., 2019). The final two reports we were able to locate centred on male firefighters in Poland, and found that their perceptions of life stress were consistently correlated with most of the domains normally associated with burnout (notably, these reports used an instrument that assessed general life stress, not just stress originating from work) (Makara-Studzińska et al., 2019, 2020).

Author, Year of Publication (DRS)	Study Location	Study Design	Sample Size	Psychosocial Stress Measurement Tool	Health Outcome; Measurement Tool	Core Results: *narrative*	Core Results: *quantitative*
Angelo & Chambel, 2015 (6/8)	Portugal (sampling from all 18 districts)	longitudinal (panel design with two waves of data collection)	586 men 65 women	Organisational Demand Scale	burnout; emotional exhaustion and cynicism sub-scales of the Maslach burnout inventory, general version	Increased perception of organisational demands predicted likelihood of burnout, which, in turn, was associated with an altered perception of job demands.	organisational demands had a positive, cross-lagged effect on burnout ($\beta = 0.10$, $p < .05$)
Makara-Studzinska et al., 2019 (8/8)	Poland (sampling from 12 different provinces)	cross-sectional	580 men	Perceived Stress Scale	burnout; Link Burnout Questionnaire (LBQ)	Perceived stress was associated with most domains measured by the LBQ (psychophysical exhaustion, sense of professional inefficacy, disillusion), but not all (relationship deterioration).	perceived stress significantly influenced psychophysical exhaustion ($\beta = 0.92$, $p < .001$), sense of professional inefficacy ($\beta = 0.61$, $p = .005$), and disillusion ($\beta = 1.64$, $p = .004$)

Makara-Studzinska et al., 2020 (5/8)	Poland (sampling from 12 different provinces)	cross-sectional	576 men	Perceived Stress Scale	burnout; Link Burnout Questionnaire (LBQ)	Perceived stress was correlated with all 4 domains captured by the LBQ.	perceived stress was significantly correlated with psychophysical exhaustion (r = .49, p < .001), relationship deterioration (r = .30, p < .001), sense of professional inefficacy (r = .36, p < .001), and disillusion (r = .46, p < .001)
Mitani et al., 2006 (4/8)	Japan (1 rural fire service, 1 urban fire service)	cross-sectional	237 men 4 women	Japan Brief Job Stress Questionnaire	burnout; Maslach burnout inventory	Social support was negatively correlated with, and job stress was positively correlated with, certain burnout sub-scales (emotional exhaustion and de-personalisation).	social support (r = -.32, p < .01) and job stress (r = .60, p < .01) were correlated with emotional exhaustion social support (r = -.36, p < .01) and job stress (r = .51, p < .01) were correlated with depersonalisation

Smith et al., 2019 (8/8)	southeastern USA (urban setting)	cross-sectional	198 men 10 women	Perceived Work Stress Scale (derived from Cohen's Perceived Stress Scale)	burnout; Malach-Pines burnout scale	Work stress showed a strong, positive association with burnout.	work stress significantly predicted burnout ($\beta = 0.50$, $p < .01$)

Table 9. Characteristics and key findings from studies examining the relationship between psychosocial stressors and burnout in firefighters. CI, confidence interval; DRS, design and reporting score; LBQ, Link burnout questionnaire; OR, odds ratio.

6.4.5 Psychosocial stressors and alcohol use disorders

Alcohol use disorders encompass a variety of health risk behaviors, including excessive drinking and driving while impaired, which may have profound effects upon both the individual and those around them (Schuckit, 2009). In our scan of the literature, we found four reports that examined the interaction between psychosocial stress and patterns of alcohol use within firefighters (**Table 10**). The largest study that we encountered involved 6484 male and 667 female firefighters from South Korea, and found that perceived job stress significantly predicted an increased likelihood of alcohol abuse (J. I. Kim et al., 2018). Using the same tool to assess problems with alcohol use, Hosoda et al. (2012) found that having a poor perception of their workplace environment was a key factor influencing alcohol dependence among male Japanese firefighters. With a focus on a large group of North American female firefighters, Jahnke et al. (2019) observed that those with the highest level of perceived discrimination and harassment had a clearly elevated risk of alcohol abuse (OR 1.54; 95% CI: 1.09, 2.17). Unlike the other reports on this topic, the final one that we discovered used a general measure of psychosocial stress (as opposed to an instrument concentrated upon work-related stressors), but still observed that levels of alcohol abuse rose with levels of perceived stress (Arbona et al., 2017).

Author, Year of Publication (DRS)	Study Location	Study Design	Sample Size	Psychosocial Stress Measurement Tool	Alcohol Abuse Measurement Tool	Core Results: *narrative*	Core Results: *quantitative*
Arbona et al., 2017 (6/8)	southwestern USA (urban setting)	cross-sectional	1036 men	Perceived Stress Scale (PSS-10)	Rapid Alcohol Problems Screen (RAPS-4)	Higher levels of perceived stress were observed among those with higher levels of alcohol abuse.	greater RAPS-4 scores significantly predicted greater PSS-10 scores [β(black) = 0.13; β(Latino) = 0.22; $p < .001$]
Hosoda et al., 2012 (4/8)	Tottori prefecture, Japan	cross-sectional	246 men	Brief Job Stress Questionnaire	alcohol use disorders identification test (AUDIT)	A poor perception of one's workplace environment showed a positive relationship with alcohol dependence.	perceptions of workplace environment and AUDIT scores were significantly correlated ($r = .13$, $p = .047$)
Jahnke et al., 2019 (8/8)	USA and Canada	cross-sectional	1773 women (~98% from USA)	Chronic Work Discrimination and Harassment, abbreviated scale	CAGE questionnaire	The risk of alcohol abuse increased with the level of perceived discrimination and harassment.	those with the highest level of perceived discrimination and harassment had an elevated risk of alcohol abuse (OR = 1.54; 95% CI = 1.09, 2.17)

Kim et al., 2018 (8/8)	Gyeonggi province, South Korea	cross-sectional	6484 men 667 women	Korean Occupational Stress Scale, short form	Alcohol Use Disorders Identification Test (AUDIT)	Perceived job stress was associated with an increased likelihood of alcohol abuse.	AUDIT scores significantly predicted greater perceived stress (β = 0.007, $p < .001$)

Table 10. Characteristics and key findings from studies examining the relationship between psychosocial stressors and alcohol abuse in firefighters. AUDIT, alcohol use disorders identification test; CAGE, "cut-annoyed-guilty-eye"; CI, confidence interval; DRS, design and reporting score; OR, odds ratio; PSS, perceived stress scale; RAPS, rapid alcohol problems screen.

6.4.6 Psychosocial stressors and sleep quality

An adequate amount of restful sleep is not only essential for proper cognitive function, but its absence is also a notable risk factor for a variety of health problems ranging from impaired mood to workplace injury (E. K. Lee & Douglass, 2010; Uehli et al., 2014). We found three studies that investigated the association between various psychosocial stressors and the quality of sleep among firefighters (**Table 11**). Although, Haddock et al. (2013) observed that American firefighters who worked longer shifts (48-hour shifts) were significantly more likely to experience excessive daytime sleepiness (EDS) compared with their counterparts who worked 24-hour shifts, the level of EDS was not influenced by the degree of perceived general life stress. In a similar fashion, work-related psychosocial stress was not able to predict poor sleep quality amongst a large sample of Korean firefighters (although, many occupational stress factors were correlated with sleep quality)(Lim et al., 2014). By contrast, Yook (2019) using very similar tools to measure both work stressors and sleep quality within Korean firefighters, noted a graded relationship wherein increasing occupational stress was linked with declining sleep quality.

Author, Year of Publication (DRS)	**Study Location**	**Study Design**	**Sample Size**	**Psychosocial Stress Measurement Tool**	**Health Outcome; Measurement Tool**	**Core Results:** *narrative*	**Core Results:** *quantitative*
Haddock et al., 2013 (6/8)	midwestern USA (11 sites in 8 states)	cross-sectional	458 men	Perceived Stress Scale	excessive daytime sleepiness (EDS); Epworth sleepiness scale	Perceived stress was not associated with excessive daytime sleepiness.	the effect size (Cohen's d) of the difference in perceived stress between those with and without off-duty EDS was 0.16
Lim et al., 2014 (5/8)	South Korea (metropolitan region)	cross-sectional	657 men	Korean Occupational Stress Scale (KOSS), short form	sleep quality; Pittsburgh Sleep Quality Index, Korean version	Although occupational stress was correlated with most KOSS sub-scales, total stress was not able to predict poor sleep quality.	occupational stress did not increase risk for poor sleep quality (OR = 0.93; 95% CI = 0.93, 2.72)

Yook, 2019 (7/8)	Seoul, South Korea	cross-sectional	705 men	Korean Occupational Stress Scale	sleep quality; Pittsburgh Sleep Quality Index (PSQI), Korean version	Occupational stress impaired each of the seven sub-factors measured by the PSQI.	occupational stress was significantly correlated with a reduced PSQI score (r = .276, p = .001)

Table 11. Characteristics and findings from studies measuring psychosocial stressors and their relationship with sleep disorders in firefighters. CI, confidence intervals; DRS, design and reporting score; EDS, excessive daytime sleepiness; KOSS, Korean Occupational Stress Scale; OR, odds ratio; PSQI, Pittsburgh Sleep Quality Index.

6.4.7 Psychosocial stressors, altered physiological parameters, and somatic disorders

6.4.7.1 Cardiovascular function

We found a single report (Bongkyoo Choi, Schnall, et al., 2016) investigating the association between work-related stress (particularly, concern raised by increasing job demands) and elevated blood pressure in a cohort of firefighters (**Table 12**). Using an amalgamated scale to assess work-related stress, the study revealed a clear (albeit modest) increase in systolic blood pressure amongst those who felt that their work had grown more demanding.

Heart rate variability (HRV) is a measure of periodic variation in heart rate over time that reflects autonomic nervous system function (Togo & Takahashi, 2009); although HRV is not a health outcome per se, given that work stress can affect HRV (Chandola et al., 2008) and that autonomic imbalance may be regarded as an important antecedent to heart disease (Thayer et al., 2010), we decided to include studies using the measure. We captured two studies that investigated whether job-related stressors could alter HRV in Korean firefighters. Interestingly, although each study used the same occupational stress scale, their observations were quite different. After adjusting for job characteristics, the first report found that concerns about both the occupational climate and organizational system were associated with undesirable changes in certain HRV parameters (Shin et al., 2016). By contrast, the second report observed that scores for none of the eight factors composing the Korean Occupational Stress Scale influenced any of the standard HRV parameters (Yook, 2019).

6.4.7.2 Musculoskeletal disorders

Work-related musculoskeletal disorders (WMSD) encompass a range of conditions that may interfere with employee health and job performance, including lower back pain, muscle sprains, and ligament damage (Punnett & Wegman, 2004). Of the WMSDs typically experienced by firefighters, back pain appears to be the most common complaint, and we located two reports that examined its relationship with occupational stress (**Table 12**). Using a very large sample of male Korean firefighters, M. G. Kim et al. (2016) observed that the risk of back pain was clearly affected by two key occupational factors, organizational injustice (OR 1.53; 95% CI: 1.04, 2.24) and high job demands (OR 1.55; 95% CI: 1.35, 1.77). However, in a comparatively smaller sample of male American firefighters Damrongsak et al. (2017) did not find that back pain could be predicted with job-related stress (although a participant's age and history of back pain were highly predictive).

In the same large sample of Korean firefighters noted earlier, M. G. Kim et al. (2013) found that the risk of WMSDs was affected by several occupational factors, although lack of reward (OR 2.39; 95% CI: 1.08, 5.26) and high job demands (OR 1.52; 95% CI: 1.35, 1.70) were the most influential. Similarly, in a smaller, albeit mixed gender, sample of European firefighters, those with the greatest level of work-related stress, had an increased risk of musculoskeletal problems (OR 1.52; 95% CI: 1.02, 2.25) (Soteriades et al., 2019).

6.4.7.3 Gastrointestinal disorders

Functional gastrointestinal disorders may affect multiple sites along the length of the digestive tract, and we captured two studies that investigated whether risk for these illnesses may be affected by psychosocial work-place stressors using the same large, mixed gender cohort of Korean firefighters (**Table 12**). The first study, Jang et al. (2016) revealed that several occupational factors increased risk for gastro–oesophageal reflux disease, with lack of reward (OR 2.17; 95% CI: 1.21, 3.88) and interpersonal conflict (OR 2.07; 95% CI: 1.06, 3.51) exerting the most influence. The other report focused upon irritable bowel syndrome, but also observed that lack of reward (OR 2.39; 95% CI: 1.08, 5.26) and interpersonal conflict (OR 2.21; 95% CI: 1.25, 4.33) were the most impactful of the occupational characteristics that showed a relationship (Jang et al., 2017).

Author, Year of Publication (DRS)	**Study Location**	**Study Design**	**Sample Size**	**Psychosocial Stress Measurement Tool(s)**	**Health Outcome; Measurement Tool**	**Core Results:** *narrative*	**Core Results:** *quantitative*
Choi et al., 2016 (6/8)	USA (Southern California)	cross-sectional	321 men 9 women	Job Content Questionnaire Effort-Reward Imbalance Questionnaire	hypertension; systolic BP ≥140 mmHg, diastolic BP ≥ 90 mmHg, or anti-hypertensive medication use	Systolic BP was slightly higher among male firefighters who felt their job had grown more demanding over the past few years.	those who perceived an increase in work demand displayed a slight increase in BP (2.7 mmHg; $p = .058$)
Damrongsak et al., 2017 (6/8)	USA (southeastern urban centre)	cross-sectional	298 men	Job Stress Survey	back pain; health risk appraisal questionnaire	Occupational stress was not observed to increase risk for current back pain.	occupational stress (particularly, job pressure and lack of organisational support) did not increase risk for current back pain (OR = 1.02; $p = .17$)

Jang et al., 2016 (6/8)	South Korea	cross-sectional	1140 men 77 women (same data set used in Jang et al., 2017)	Korean Occupational Stress Scale	gastro-oesophageal reflux disease (GERD); Montreal criteria	Job demands, interpersonal conflict, lack of reward, and occupational climate increased risk for GERD.	(OR; 95% CIs) job demands (1.83; 1.34, 2.52) interpersonal conflict (2.07; 1.06, 3.51) lack of reward (2.17; 1.21, 3.88) occupational climate (1.49; 1.09, 2.02)
Jang et al., 2017 (6/8)	South Korea	cross-sectional	1140 men 77 women (same data set used in Jang et al., 2016)	Korean Occupational Stress Scale	functional gastrointestinal disorders of the digestive system (FGIDS); Rome III criteria	Job demands, interpersonal conflict, and lack of reward increased risk for FGIDS.	(OR; 95% CIs) job demands (1.79; 1.11, 2.89) interpersonal conflict (2.21; 1.25, 4.33) lack of reward (2.39; 1.08, 5.26)

Kim et al., 2013 (4/8)	South Korea	cross-sectional	21,466 men (same data set used in Kim et al., 2017)	Korean Occupational Stress Scale, short form	work-related musculoskeletal disorders; Korean National Institute of Occupational Safety and Health Symptom survey	Job demands, job insecurity, organisational system, lack of reward, and occupational climate increased risk for musculoskeletal disorders.	(adjusted OR; 95% CIs) job demands (1.52; 1.35, 1.70) job insecurity (1.14; 1.01, 1.28) organisational system (1.37; 1.21, 1.58) lack of reward (2.39; 1.08, 5.26) occupational climate (1.24; 1.11, 1.40)

Kim et al., 2017 (4/8)	South Korea	cross-sectional	24,209 men (same data set used in Kim et al., 2013)	Korean Occupational Stress Scale, short form	lower back pain; Korean Occupational Safety and Health Agency screening criteria	Job demands, and organisational injustice increased risk for lower back pain in a graded manner.	(adjusted OR; 95% CIs) job demands (1.55; 1.35, 1.77) organisational injustice (1.53; 1.04, 2.24)
Shin et al., 2016 (3/8)	South Korea	cross-sectional	645 men	Korean Occupational Stress Scale	heart rate variability (HRV); measured in time and frequency domains	After adjustment, occupational climate and organisational system reduced certain HRV parameters.	low assessment of occupational climate reduced HRV parameters in both time and frequency domains ($p < .05$); low view of organisational system reduced HRV in a frequency domain parameter ($p < .05$)

Soteriades et al., 2019 (5/8)	Cyprus	cross-sectional	380 men 50 women	Copenhagen Psychosocial Questionnaire, stress sub-scale	musculoskeletal (MSK) problems; Nordic Musculoskeletal Questionnaire	Increased work-related stress was associated with more MSK problems.	those scoring above the mean level on the stress sub-scale had an increased risk of MSK problems (OR = 1.52; 95% CI = 1.02, 2.25)
Yook, 2019 (7/8)	Seoul, South Korea	cross-sectional	705 men	Korean Occupational Stress Scale	heart rate variability; measured in time and frequency domains	Occupational stress was not able to predict HRV in either the time, or frequency domain.	occupational stress was not correlated with HRV domains: SDNN (r = .027, p = .47), RMSSD (r = .036, p = .34), logLF (r = .011, p = .77), logHF (r = .008, p = .84)

Table 12. Characteristics and key findings from studies examining the relationship between psychosocial stressors and physiological parameters and somatic disorders in firefighters. Abbreviations: BP, blood pressure; CI, confidence interval; DRS, design and reporting score; FGIDS, functional gastrointestinal disorders of the digestive system; GERD, gastro-oesophageal reflux disease; HF, high-frequency band; HRV, heart rate variability; LF, low-frequency band; MSK, musculoskeletal; OR, odds ratio; RMSSD, root mean square of successive differences between heartbeats; SDNN, standard deviation of the normal-to-normal sinus-initiated inter-beat interval.

6.5 Discussion

6.5.1 Main findings of the study

The aim of our review was to survey the research landscape to provide evidence about whether the work-related psychosocial stressors experienced by firefighters could alter the likelihood that they would experience undesirable health-related changes. As was expected, we found that job-related stress could influence firefighter health; however, we were surprised by the breadth of areas affected, which included depression, anxiety, burnout, alcohol use, sleep quality, cardiovascular activity, musculoskeletal problems, and gastrointestinal function. In addition, we observed that the health-related resilience of firefighters in the face of occupational stressors could be moderated by a small collection of factors: some of these variables seemed to promote resilience (self-esteem, social support, and distress tolerance), whereas others seemed to discourage resilience (interpersonal conflict, discrimination-harassment, and perceptions of workplace fairness).

Of the health problems we found that were associated with occupational stressors, a few were particularly notable; first among these were depressive symptoms, which seemed to accompany higher levels of work-related psychosocial stressors amongst firefighters from several international jurisdictions. In each of these studies, the demands placed upon participants (in the form of factors such as intergroup conflict and perceived discrimination) were able to (presumably)exceed the available countervailing resources, and the imbalance may help to explain why the prevalence of depression in the fire service tends to exceed that observed in the general population (An et al., 2015; Fullerton et al., 2004). As well, given that depression is an established risk factor for suicidal ideation, the inability to counterbalance job-related psychosocial demands may be one of the upstream reasons underlying why firefighters are at increased risk for suicide (Stanley et al., 2015, 2016). Interestingly, the clear link observed between perceived discrimination-harassment And depressive symptoms in female firefighters (Jahnke et al., 2019) may help to explain why H. Park et al. (2019) found that female gender was a risk factor for suicidal ideation within Korean firefighters.

Along with depression, burnout consistently appeared as a serious psychological effect of long-term exposure to a difficult and demanding work environment. Although burnout is a multi-faceted psychological syndrome (Maslach et al., 2001), emotional exhaustion (a decrease in the energy, or desire to perform work) and emotional withdrawal (a disengagement from work) are two of its characteristic features; importantly, both of these elements tended to be seen in firefighters with high levels of perceived stress. In an attempt to alleviate the changing perceptions of work and diminished job satisfaction that arise with burnout, firefighters may engage in short-term displacement behaviors, like alcohol use (Bacharach et al., 2008). Indeed, we observed that a high level of perceived stress (caused by factors such as a poor perception of one's work environment, discrimination-harassment, or an inability to cope) significantly predicted a higher level of alcohol abuse among firefighters. As a result, although the excessive alcohol use that has been observed within the fire service is likely attributable to the effects of traumatic exposure, work-related psychosocial stressors (either directly, or upstream of burnout) may also play a role in the development of this behavior (Hosoda et al., 2012; J. I. Kim et al., 2018; Piazza-Gardner et al., 2014; Zegel et al., 2019).

Although increased risk for depressive symptoms, burnout,and alcohol use disorders were among the clearest outcomes of job-related psychosocial stressors that we found, we also observed that cardiovascular, musculoskeletal, and gastrointestinal disorders were often associated with undesirable levels of stress. A number of earlier reports have shown that firefighters do experience a level of cardiovascular disease greater than the general population (Kales et al., 2007; Soteriades et al., 2011), and suggest that this increased prevalence is likely attributable to variables such as shift work and irregular physical exertion; however, we found studies showing that a poor "organizational system" (characterized by features such as unfair organizational policies, organisztional injustice, and unsatisfactory organizational support) was associated with both increased pulse wave velocity (a measure of arterial stiffness) (Yook, 2019) and decreased HRV (periodic variation in heart rate) (Shin et al., 2016), both of which have been shown to increase risk for mortality related to cardiovascular disease (Hamer et al., 2008).

Work-related psychological burden may also activate a cascade of events, including increased muscle tone/activity (leading to fatigue), slower recovery, intensification of pain perception, weakened pain coping mechanisms, increased inflammation, and diminished circulation and supply of oxygen to tissues, that influence the development of musculoskeletal problems (M. G. Kim et al., 2013; Visser & Diee, 2006). As well, psychosocial factors may exert a substantial effect on gastrointestinal disorders in firefighters; however, interestingly, a poor organizational system was more closely related to irritable bowel syndrome, whereas an unfavorable occupational climate seemed more likely to affect gastro–oesophageal reflux disease risk. Although the mechanisms that may underlie the connection between psychosocial stress and gastrointestinal function remains unclear, a dysregulated gut–brain axis, alterations to the gut microbiome, and a reduction in gut motility are all factors proposed as playing a role in the onset and exacerbation of symptoms (Jang et al., 2016, 2017).

6.5.1.1 Factors moderating work-related psychosocial stress in firefighters

A job demands–resources framework suggests that each job makes varied demands on an employee, and that the efforts needed to respond to these demands can deplete a person's energy and impair their health and well-being; in addition, the model suggests that there are resources available to employees that may help them to address work-related stressors (Demerouti et al., 2001). One of the most important resources that workers may use to counterbalance demands is resilience, which is often described as a cognitive factor that assists adaptation to difficult circumstances despite previous adverse experience (Luthar & Cicchetti, 2000). Resilience has been found to reduce the probability that a stressor leads to psychiatric problems (Edwards et al., 2014; Green et al., 2010), and has been observed to buffer the impact of traumatic events on the development of PTSD symptoms in firefighters (J. S. Lee et al., 2014). During the review of those studies that formed our data set, we began to see a pattern emerge with regards to resilience among firefighters: certain variables seemed likely to enhance resilience (self-esteem, distress tolerance, and social support), whereas several others seemed likely to diminish resilience (interpersonal conflict, discrimination-harassment, and a poor perception of workplace fairness). The first factor that seemed able to promote resilience was self-esteem. In particular, a pair of reports from Japan showed that low self-esteem was the variable displaying the strongest association with increased risk for depressive symptoms (Saijo et al., 2007, 2008). A subsequent report by the same group also connected low levels of self-esteem with an increased likelihood to experience PTSD symptoms (Maslach et al., 2001). Indeed, the apparent ability of self-esteem to buffer the effects of job-related stress agrees with an earlier report that examined American firefighters (Petrie & Rotheram, 1982), and resonates with other work showing that self-esteem is both related to depression and critical to mental and physical health (Mann et al., 2004; Whisman & Kwon, 1993).

The second resilience-promoting resource that emerged was the perceived, or actual ability to endure negative emotional, or physical states, which may be captured by a pair of conceptually similar constructs: distress tolerance and self-efficacy. In a large sample of American firefighters, Stanley et al. (2018) showed that distress tolerance was able to buffer the effects of occupational stress upon suicidality among firefighters. As well, in a similarly large group of Polish firefighters, Makara-Studzinska et al. (2019, 2020) observed that self-efficacy clearly moderated the effect of perceived stress upon burnout; indeed, the studies found that regardless of the level of perceived stress, lower levels of self-efficacy evoked stronger feelings of psychophysical exhaustion. Interestingly, the studies that we examined agreed with earlier work by Regehr et al. (2003) which discussed the importance of self-efficacy as a moderator of the effect that trauma can have upon new firefighter recruits. Given that firefighters may experience the awareness of imminent dangers that could challenge them to the limit of their abilities, their level of distress tolerance (or self-efficacy) is a particularly valuable cognitive resource.

The final element that seemed to boost resilience was social support, which agrees with earlier work showing that camaraderie may be a more important predictor of mental health in firefighters than general global resources (Tuckey & Hayward, 2011). For example, as levels of perceived support decreased, regardless of whether the source was from managers, family, or friends, the manifestation of symptoms linked to depression increased (Saijo et al., 2007, 2008); as well, a relationship between psychosocial stress and suicidal ideation was observed only amongst firefighters who reported feeling an inadequate level of social support(Carpenter et al., 2015). Importantly, these findings are consistent with previous studies that explored the effect of social support on depression in both first responders and the general population (K. Park et al., 2004; Prati & Pietrantoni, 2010). As well, firefighters who lacked social support (from co-workers and family) experienced more negative symptoms of burnout (ie, emotional exhaustion and depersonalization), which suggests that perceived social support provides a feeling of belonging and enhances the capacity to manage stress (Mitani et al., 2006). Lastly, findings that show a positive association of PTSD with low social support suggest that an inadequate degree of perceived social support might amplify the risk for this psychopathology by impacting the interpretation of potentially traumatic events (E. C. Meyer et al., 2012; Saijo et al., 2012).

Of the variables that seemed likely to reduce resilience, the first that we consistently observed was interpersonal conflict. For instance, relationship conflicts within a large sample of British firefighters emerged as a key determinant of work-related anxiety and depression (Payne & Kinman, 2019). In a similar manner, work with Japanese firefighters also found that inter-group conflict threatened mental well-being among firefighters by elevating risk for depressive symptoms (Saijo et al., 2007, 2008). Notably, friction amongst those in the fire service may have effects that extend beyond mental health; for example, Jang et al (2016, 2017) observed that high levels of inter-personal conflict increased the probability of gastrointestinal disorders. Conflicts within an organization likely impair health not just by acting as an undesirable job demand, but also by reducing the likelihood that an individual may seek support for problems; that is, conflict may prevent a person from receiving the social support known to promote resilience.

The second factor that we found had the potential to drain away resilience was discrimination-harassment; although this variable may be regarded as a sub-type of inter-personal conflict, given its unique character and established effect upon occupational health disparities (Okechukwu et al., 2014; Xu & Chopik, 2020), we decided to note it separately. Although we found only a single report that directly measured perceived discrimination-harassment (Jahnke et al., 2019), both the sample size of the report and (more notably) the clear associations that it presented warranted close attention. In particular, the authors found that risk for anxiety, depression, and alcohol use disorders all clearly rose with the level of perceived discrimination-harassment. The observations are especially important given previous work showing that female firefighters do experience greater levels of discrimination-harassment relative to their male counterparts (Griffith et al., 2016). In addition, although they did not focus upon workplace discrimination-harassment, the report by Arbona et al. (2017) which involved Black and Latino firefighters in the United States, also revealed that risk for alcohol use disorders rose with the degree of perceived stress (at least some of which may be attributable to the experience of discrimination-harassment) (Perez et al., 2015; D. R. Williams, 2003).

The remaining variable that seemed able to interfere with resilience was whether a firefighter viewed their work environment in a poor light. For example, An et al. (2015) found that the risk of depression rose as firefighters viewed their workplace less favorably, whereas Hosoda et al. (2012) observed that a poor view of one's work environment was significantly correlated with alcohol dependence. Interestingly, a negative view of one's working climate was also shown to increase risk for gastrointestinal problems, musculoskeletal disorders, and lower back pain (Jang et al., 2016; M. G. Kim et al., 2013, 2016). As the transactional model of stress advances the view that stress results from a person's interactions with their environment and how they perceive and appraise these interactions (Smith et al., 2019), the widespread health effects of negatively viewing a workplace are not surprising. Of course, one of the reasons that addressing a negative view of the workplace may be particularly challenging is that, although subjectively clear and meaningful, the problem can be difficult to objectively identify.

6.5.2 Limitations of the current review

When viewing the outcomes of our review, a few methodological considerations should be noted. First, due to our review of only articles published in the English language, the possibility exists that we failed to include relevant research. As well, as we only assessed published studies, a source selection (ie, publication bias) may have affected our study. Furthermore, most of the included studies were based on a cross-sectional design, which limits the ability to draw definitive causal connections. Finally, any interpretation of our results should also carefully consider the substantial variability we observed in how work-related psychosocial stress among firefighters was measured. The questionnaires used across the reviewed studies varied according to geographical settings and needs, length, and the particular features of stress being appraised, which (understandably) leads to variability in the characteristics and magnitude of psychosocial stress being measured. Considering the mentioned limitations, our findings should be considered cautiously.

6.6 Conclusions and implications for research and public health

To the best of our knowledge, our systematic review represents the first attempt to broadly identify health outcomes related to the psychosocial stressors encountered by those within the fire service. Our work identified both the variety of psychosocial stressors experienced by firefighters and that these factors had considerable reach, given evidence for their effect upon depression-suicidality, non-depressive mental health problems, burnout, alcohol use disorders, sleep quality, and physiological parameters and somatic disorders. In an attempt to further understand the nature of the relationships at play, future research should include either efforts to build consensus around a pre-existing tool that may be used to assess psychosocial stress within firefighters (a move that seems to have already occurred within the Korean research community), and/or to craft an instrument that would have the degree of broad appeal needed to be adopted as the standard measurement tool. In addition, given the apparent lack of prospective studies, future work should strive to include longitudinal designs aimed at securing evidence of causal relationships. As well, our hope is that some of the work to be done in the area will examine how the experience of stress becomes biologically embedded in a manner that leads to the health and behavior-related changes observed; in particular, we would be keen to see measurements of the physiological imprint that can be left by stress ie, AL (Mauss, Li, et al., 2015).

With regards to occupational health and well-being, the results from our review will add to the growing body of evidence suggesting that work-related psychosocial stressors play an important role in the development of risk for a wide variety of undesirable health outcomes and behaviors. Although we certainly need to improve our understanding of how psychosocial stress becomes biologically embedded in such a way as to affect disease risk, the available evidence points to reasonably straightforward interventions that could both help mitigate unfavorable health outcomes and yield broader benefits. In particular, stakeholders should consider how policies within their institutions may be developed with the goal of promoting and preserving resilience within firefighters by encouraging self-esteem, social support, distress tolerance, and a positive view of their workplace, while discouraging interpersonal conflict and discrimination-harassment.

Chapter 7

BIOLOGICAL EMBEDDING OF PSYCHOSOCIAL STRESSORS WITHIN A SAMPLE OF CANADIAN FIREFIGHTERS: AN EXPLORATORY ANALYSIS[3]

7.1 Abstract

Objective: We wanted to determine whether the biological embedding of perceived psychosocial stress could be observed within a sample of Canadian firefighters.

Methods: We collected sociodemographic and general health-related information from 58 firefighters. As well, measures of work-related and general-life psychosocial stress, perceived social support, and physiological parameters thought to reflect the embedding of stress were gathered and analysed using ANOVA and linear regression models.

Results: Despite observing a positive relationship between psychosocial stress and allostatic load, the association was non-significant; however, age did significantly predict allostatic load ($B = .09$, $p = .04$). Notably, our participants reported abundant social support that was inversely associated with perceived stress.

Conclusions: Although perceived stress did not significantly affect allostatic load in our sample, high levels of social support may have provided an essential countervailing force.

keywords*:* allostatic load, emergency responders, psychological stress, social support

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[3] This study was accepted and published in the Journal of Occupational and Environmental Medicine on May 11, 2022. Citation of the published version: Igboanugo, S., Chaurasia, A., Bigelow, P. L., & Mielke, J. G. Biological embedding of psychosocial stressors within a sample of Canadian firefighters: an exploratory analysis. *Journal of Occupational and Environmental Medicine*, 10-1097.

7.2 Introduction

Along with fire suppression, firefighters often attend to a wide range of emergencies, including hazardous material spills, large-scale community disasters, and medical emergencies (Fisher & Etches, 2003). Coinciding with the public face of their work, firefighters, in many cases, must also manage less apparent demands, such as rotating shift work (Bongkyoo Choi, Schnall, et al., 2016; Haddock et al., 2013), interpersonal/organisational conflict (Jang et al., 2016, 2017), and an organisational system that can often be described as exhausting (M. G. Kim et al., 2013; Lim et al., 2014). As a result, together with the physical risks associated with their profession, firefighters are also likely to experience a significant degree of strain attributable to psychosocial stressors.

Work-related psychosocial stress may best be described as a combination of occupational events and characteristics that bring about a psychologically-mediated stress reaction that (importantly) has the potential to produce both short-term strains and longer-term changes in health and well-being (Ganster & Rosen, 2013). Notably, psychosocial stressors in the workplace have become the subject of growing interest, as mounting evidence points to a significant link between this form of stress and adverse health outcomes, including chronic disease development and progression (Ganster & Rosen, 2013; O’Connor et al., 2021).

Given their likelihood of experiencing psychosocial stress and its potential amplification by the organisational culture and structure of the urban fire service, firefighters may be susceptible to a wide range of somatic, mental, and behavioural health challenges

(Fisher & Etches, 2003; Igboanugo et al., 2021). In addition to their effects on individual firefighters, these health challenges may have broader public implications in the form of increased rates of absenteeism, sick days, long-term disability, increased turnovers, early retirements, and increased healthcare spending (Fisher & Etches, 2003).

Although psychosocial stress presents a significant workplace hazard, there are differing views regarding its measurement and the mechanism whereby its experience may affect worker health. Moreover, since most of the current evidence relating to stress perception and assessment amongst firefighters has relied on the subjective measurement of stress (e.g., self-report questionnaires, interviews), questions still linger regarding the physiological imprint that may be left by psychosocial stress. As a result, an objective measurement of stress embedding (i.e., how stress affects the body and overcomes its defences) has become essential. Significantly, over the past three decades, efforts from several fields have helped develop the concept of allostatic load, an objective assessment of the burden imposed by stressors upon the body.

By combining many of the classical stress-response ideas of Selye's work with the more recently developed appreciation for the importance of cognitive appraisal, allostatic load attempts to measure the cumulative effects of the body's efforts at adapting to stressful stimuli by examining multiple physiological changes (McEwen & Stellar, 1993). Quite simply, the repeated need to respond to environmental challenges comes with a cost in the form of changes across a variety of areas (particularly in the cardiovascular, metabolic, neuroendocrine, and immune systems) that can gradually increase the risk for both disease and mortality (Guidi et al., 2021; Seeman et al., 1997).

Several observational and longitudinal studies have provided evidence linking repeated exposure to work-related psychosocial stressors with high allostatic load and adverse health outcomes (Bellingrath et al., 2009; J. Sun et al., 2007). Possibly, a similar situation may occur in firefighters, and such stressors may not only "get under their skin" in a fashion that increases their risk for disease, but may also lead to behavioural issues with health consequences, such as problematic alcohol use (Hosoda et al., 2012; Lupien et al., 2018).

As with other workers, the sequence of events leading from perceived psychosocial stress to allostatic load may be affected by different factors. For example, a clear relationship between ageing and increased allostatic load has been found previously (Crimmins et al., 2003; Seeman et al., 2001). Therefore, the age-allostatic load relationship was expected, given that the multi-dimensional change in physiology captured by allostatic load reflects the gradual change in the body's function over the lifespan (Guidi et al., 2021; Read & Grundy, 2014). Further, since firefighters typically devote many years of their lives to the profession, during which they are likely exposed to a constant set of stressors, one critical determinant of allostatic load development may be their length of professional service. Indeed, essential health changes, such as the increased prevalence of musculoskeletal and mental health disorders (such as anxiety and depression), have been observed among firefighters over their careers (Goh et al., 2020; Negm et al., 2017). As well, given that social support has been shown to boost resilience amongst firefighters by providing a feeling of acceptance and camaraderie, and has been consistently shown to cushion the effect of stress exposure in these workers, this cognitive resource may act as an additional variable influencing the accumulation of allostatic load (Beaton & Murphy, 1993; Regehr, 2009; Regehr et al., 2003).

While earlier studies have examined both objective and subjective measures of stress in firefighters, to the best of our knowledge, there has not yet been an attempt made to directly examine the association between work-related psychosocial stress and allostatic load in this group of workers. Therefore, the primary aims of our study were: (a) to learn what values for the physiological parameters contributing to allostatic load might be expected in a sample of Canadian firefighters and (b) to use these data to explore whether the psychosocial stressors faced by firefighters may become biologically embedded such that their risk of developing adverse health outcomes was increased. With the stated goals in mind, our cross-sectional study used the allostatic load framework to investigate three hypotheses. First, a firefighter's age and service length would impact their reported stress level and allostatic load. We would observe higher perceived stress levels and allostatic load among older and longer-serving firefighters. Second, firefighters reporting higher perceived psychosocial stress would also display a more significant allostatic load. Finally, we predicted that feelings of social support would moderate any observed effect perceived stress might have on allostatic load amongst participants.

7.3 Materials and Methods

7.3.1 Study Population

We recruited 64 professional firefighters from Waterloo Fire Rescue, which serves the City of Waterloo in Ontario, Canada. After providing informed consent, participants completed a set of questionnaires and permitted the collection of physiological measurements (to be described in a subsequent section). Between October 2019 and January 2020, data were collected on weekdays between 9:00 am and 12:00 noon, and always took place during a participant's first shift following two days away from work. Participants were not excluded based on medical history or medication use; however, these data were collected and considered during data analysis. The Office of Research Ethics at the University of Waterloo approved the study.

7.3.2 Questionnaire-based Measurements

On each day of data collection, questionnaires were administered in a standardised fashion to collect information on three topics: general demographic and health characteristics, perceptions of social support from family, friends, and work colleagues, and impressions of both work and general life stress. The demographic questionnaire captured each participant's age, gender, ethnicity, primary language, and length of service as a firefighter. The general health survey (using questions modelled on the Canadian Community Health Survey) broadly assessed a participant's medical history (e.g., presence of hypertension, or diabetes mellitus) and health risk behaviours (e.g., alcohol use, smoking, and level of physical activity). In subsequent sections, instruments relating to our measurement of perceived social support and psychosocial stress will be discussed.

7.3.3 Social Support

We measured perceived social support using two questionnaires: the Multi-dimensional Scale of Perceived Social Support (MS-PSS), and the Social Support Scale for Firefighters (SSS-FF). The MS-PSS is a 12-item questionnaire designed to assess perceived support from three primary areas over the past six months: family, friends, and a significant other (Zimet et al., 1988). Before the study, we were unaware of how many participants would have a partner, so we removed the four items assessing support from a "significant other" to yield an 8-item questionnaire focused on family and friends. The modified scale used a 5-point Likert response format ranging from "strongly disagree" to "strongly agree", with higher scores indicating a greater level of perceived social support. The original version of the MS-PSS (Zimet et al., 1988) displayed a high internal consistency ($\alpha = .88$), which agrees with what we observed in our sample ($\alpha = .86$; **Table 14**).

The SSS-FF (Carpenter et al., 2015) contains 9-items that measure the level of social support firefighters feel they have received from colleagues over the past six months. The scale uses a 5-point Likert-based scoring system, and responses range from “strongly disagree” to “strongly agree”. The SSS-FF score is obtained by reversing the response to question 3 and then summing across all scale items, with higher scores indicating a higher degree of perceived social support. Previous research demonstrated good internal consistency (α = .81; Carpenter et al., 2015), which generally matches what was observed in our sample (α = .84; **Table 14**).

7.3.4 Psychosocial Stress

Perceptions of psychosocial stress were measured using two questionnaires: the Sources of Occupational Stress scale (SOOS-14), and the Perceived Stress Scale (PSS-10). To examine work-related psychosocial stress, we used the SOOS-14 (Kimbrel et al., 2011), which is a 14-item revised version of Beaton and Murphy's (1993) Sources of Occupational Stress scale. The SOOS-14 measures psychosocial stressors specific to firefighters (e.g., conflict with colleagues, financial strain, and feelings of isolation from family due to work demands). The SOOS-14 asks participants to consider how bothered they have felt by these stressors over the past 10 shifts (given their schedule format, ten shifts for our participants would typically take place over about three weeks). For our study, items were scored on a 3-point Likert scale (0 = not at all bothered; 1 = somewhat bothered; 2 = extremely bothered), which allowed a range from 0 to 28, with higher scores indicating higher perceived stress levels. The SOOS-14 questionnaire has exhibited good internal consistency (α = .86), and good validity coefficients across independent samples of firefighters (Carpenter et al., 2015; Kimbrel et al., 2011). In the present sample, the internal reliability of the SOOS-14 was also good (α = .81; **Table 14**).

To measure general-life stress, we used the PSS-10 [30], which is a widely used instrument for appraising the perception of stress over the past month and is scored on a 5-point Likert scale ranging from 0 (never) to 4 (very often). The PSS-10 scores are obtained by reversing responses to the four positively stated items (items 4, 5, 7, and 8) and then summing across all scale items. Individual scores on the PSS-10 can range from 0 to 40, with higher scores indicating greater perceived stress. Previous work has revealed that the PSS-10 shows good reliability with a Cronbach's alpha of .78 (Cohen & Williamson, 1988), which resonates with our current sample ($\alpha = .81$; **Table 14**).

7.3.5 Physiological Measurements

To assess the cumulative biological embedding of psychosocial stress, we measured several different physiological signs in order to calculate an allostatic load index (ALI) (Seeman et al., 1997): diastolic blood pressure (DBP), systolic blood pressure (SBP), waist-to-height ratio (WHtR), glycosylated haemoglobin (HbA1c), low-density lipoprotein (LDL), high-density lipoprotein (HDL), heart rate variability (HRV), and hair cortisol levels. The parameters chosen to determine the ALI were picked based on supporting literature (Juster et al., 2010; Mauss, Li, et al., 2015; Seeman et al., 2001). In addition, participants were advised to abstain from alcohol and heavy meals in the evening prior to data collection. They were also asked to avoid caffeine and intense physical activity on the morning of data collection.

With the participant in a relaxed and seated position, blood pressure (SBP and DBP) was measured twice, once at the start of a meeting and then again at the end, using an automated OMRON 3 Series upper arm blood pressure monitor. Height was measured with a free-standing stadiometer, and waist circumference (WC; in centimetres) was measured horizontally at the midway point along the smallest circumference between the lowest ribs and iliac crest. A simple division of the WC over height was done to determine WHtR.

Blood samples for lipid (HDL and LDL) and HbA1C analysis were collected with a finger-prick blood draw using a 2.2 mm lancet. For lipid measurement, a portion of the collected blood sample (15 - 40 μL) was placed on a test strip and inserted into a CardioChek PA analyser (PTS Diagnostic, Sunnyvale, USA). For HbA1c measurement, blood samples (5 μL) were placed on a test strip and inserted into the A1CNow+ analyser (PTS Diagnostic, Sunnyvale, USA).

Heart rate variability was recorded using the Bittium Faros ECG Ambulatory Sensor (Bittium Corporation, Finland) with an ECG sampling frequency of 1000 Hz. With participants relaxed in a seated position, the sites intended for electrode placement in the chest region were prepared with NuPrep and alcohol, with the shaving of chest hair done as needed. Snap-on electrodes were then placed firmly on three sites in the chest area (one electrode on each side beneath the midpoint of the clavicle, and one on the left 5th intercostal space at the mid-clavicular line). Signals from the Bittium Faros device were interpreted using the Cardiscope Analytic software (Smart Medical, UK); mainly, the root-mean-square differences of successive R-R intervals (RMSSD) were used.

Hair samples (about 10 g) were taken from the vertex of the scalp, with a focus on approximately the first 3 cm of the hair shaft to determine hair cortisol concentration (HCC). Each sample was taped to a collection card indicating the root end and then sealed in a labelled envelope with the participant's identification code before being sent for analysis at the Drug Safety Laboratory at Western University. A detailed description of the method used for cortisol extraction and analysis has been described by Gow et al. (2011).

To calculate the ALI, the sum of physiological measurements was computed based on parameters scoring in the highest quartile (75th percentile) of risk for the total population under study (except for HDL and HRV, where risk was defined as scores within the lowest quartile; that is, the 25th percentile) as established by Seeman et al. (1997). Hence, values falling with the high-risk threshold were scored as "1", while other values were scored as "0", and scores ranged from 0 – 8, with higher scores representing greater allostatic load.

7.3.6 Statistical Analyses[4]

We performed all statistical analyses using either SPSS statistical software for macOS (version 25; IBM SPSS, 2017), or R Studio (version 3.4.1; RStudio Inc, 2017). The data analyses were completed based on participants with a complete set of data on the variables of interest, e.g., allostatic load and psychosocial stress measures. Normality for all psychometric and biometric variables was assessed using the D'Agostino-Pearson test (Agostino et al., 1990). For variables with a skewed distribution (HbA1C, HCC, and HRV), we applied logarithmic transformation using the "LG10(x)" function in SPSS prior to further analysis.

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[4] The SPSS syntax for the statistical analyses is available in **appendix N**

For descriptive analyses, means and standard deviations (SD) were calculated for continuous variables, while frequency (*n*) and percentages were determined for categorical variables. For bivariate analysis, Pearson's correlation coefficient was used to investigate the association between age, length of service (LOS), and the individual physiological measurements collected to form the allostatic load index; as well, we examined associations between age, LOS, stress instrument scores, and levels of perceived social support. Exploratory analysis included two-tailed, independent Student's t-tests to compare mean allostatic load index (ALI) differences between 2-item categorical variables (gender, physical activity, and cigarette smoking); given that all but 2 participants identified as White/European, ethnicity was not considered. In addition, one-factor analysis of variance (ANOVA) was used to compare the mean ALI across three, or more item categorical variables (alcohol intake, time spent sleeping each night). Notably, given low participant numbers for 2 of the alcohol intake categories (never and daily), they were consolidated with their adjacent categories prior to the ANOVA.

Since there was evidence to suggest that both presentations of psychosocial stress (i.e., work-related stress and general-life stress) may significantly impact the AL of working adults to a varying degree (Mauss, Jarczok, et al., 2015; Mauss & Jarczok, 2021), and given the study's exploratory nature, we decided to examine both presentations of psychosocial stress on the AL in our sample. Subsequently, we conducted regression analyses that consisted of four models to examine the relationship between our outcome variable (the ALI) and our predictor variables (perceived psychosocial stress in the form of PSS-10 and SOOS-14) while adjusting for length of service, age, and level of perceived social support (also the moderating variable). Similarly, as we did with psychosocial stress, we included both measures (MS-PSS and SSS-FF) of social support based on the presumption that examining their effects individually rather than as a composite variable would be more informative and align better with the design principles of the study.

Hence, *model 1* tested the main effect of the core predictor (psychosocial stress) on the response variable of interest (the ALI). *Model 2* examined the potential confounding effect of age and LOS on the predictor-outcome relationship. *Model 3* involved a combination of *Model 2* and adjustment for both social support measures (MS-PSS and SSS-FF). Finally, *Model 4* combined *Model 3* and the interaction effect of both social support measures (MS-PSS and SSS-FF). Multi-collinearity based on a moderate Variance Inflation Factor (VIF; $1<VIF<5$) was accepted for analysis (Frost, 2021; Glen, 2015). The accepted level of statistical significance was set at $p < .05$.

7.4 Results

7.4.1 General Characteristics of the Study Population

The initial sample consisted of 64 firefighters; however, one participant had substantial missing questionnaire data, and five participants did not provide hair samples, so they were excluded from further analyses. Hence, as presented in **Table 13**, our final sample consisted of 52 men (90%) and 6 women (10%) with a mean age of 40 years (SD = 7.9 years, range 27 – 58 years). On average, study participants had been with Waterloo Fire Rescue for 13 years (SD = 8.0 years, range 0.3 - 32 years), and most (97%) described their ethnic background as White/European.

With regards to health-related behaviours (**Table 13**), 62% reported consuming alcohol more than twice a week (although only 2 participants consumed alcohol daily), very few had used cigarettes in the last month (10%; only one person reported smoking daily), and most (87%) had participated in sports-like activities for at least 10 minutes over the past week. As for sleeping-related activity, most firefighters (85%) in our sample reported sleeping 6, or more hours each night. However, a clear majority of participants (80%) had trouble falling, or staying asleep at least some of the time.

		Number (%)	Mean ± SD	Range
Age (years)			40 ± 7.88	27 - 58
Gender				
	male	52 (90)		
	female	6 (10)		
Ethnicity				
	White/European	56 (97)		
	all others	2 (3)		
Length of Service (years)			12.86 ± 8.00	0.30 - 32.00
	0 – 10	29 (50)		
	11 – 20	20 (34.48)		
	21+	9 (15.52)		
Smoking				
	Yes	6 (10.34)		
	No	52 (89.66)		
Alcohol Intake				
	Never	2 (3.45)		
	≤3 times a month	14 (24.14)		
	Once a week	6 (10.34)		
	2-3 times a week	28 (48.28)		
	4-6 times a week	6 (10.34)		
	Daily	2 (3.45)		
Sports/Fitness Activity (>10 min; past 7 days)				
	Yes	51 (87.90)		
	No	7 (12.10)		
Sleeping Patterns				
Amount of time spent sleeping each night.	4-6 h	9 (15.52)		
	6-8 h	43 (74.14)		
	>8 h	6 (10.34)		
Frequency of trouble falling/staying asleep.	Never	13 (22.41)		
	Sometimes	34 (58.62)		
	Most of the time	11 (18.97)		

Table 13. Demographic characteristics and health behaviours of study participants (*n* = 58). SD, standard deviation; h, hours.

7.4.2 Psychosocial Stress in the Study Population

As for perceived general life stress, the average PSS-10 score of our sample was 15.38 (SD = 4.85; **Table 14**). Notably, 76% of participants indicated they felt nervous, or "stressed" at least some of the time, while 71% of those examined sometimes felt angered by things outside their control. Further, when measuring the magnitude and nature of work-related, psychosocial stress among the participants, we observed an average SOOS-14 score of 6.22 (SD = 4.28; **Table 14**; notably, unlike other versions of the SOOS-14, ours allowed for a maximum score of 42). Although most participants (67%) reported being "somewhat bothered" by fewer than half of the items assessed, those factors that did stand out were concerns about having a poor diet, exposure to an overly demanding, or anxious co-worker, and feeling that their sleep had been disrupted.

	Mean	Standard Deviation	Range	Threshold Value (risk quartile)	Observed Cronbach's α
Psychosocial Stress Assessment					
PSS-10	15.38	4.85	4 - 29		.81
SOOS-14	6.22	4.28	0 - 19		.81
Social Support Assessment					
MS-PSS	33.59	4.15	24 - 40		.86
SSS-FF	36.53	5.01	15 - 45		.84
Allostatic Load Parameters					
Parameters with high values showing possible risk (cut-off > 75% percentile)					
Systolic Blood Pressure (mmHg)	134.67	11.32	111 - 170	≥ 142.75	
Diastolic Blood Pressure (mmHg)	79.78	8.86	59 - 105	≥ 85.50	
Waist-to-Height Ratio	0.54	0.04	0.47 - 0.64	≥ 0.57	
Glycosylated Haemoglobin (%)	5.06	0.46	4.3 - 7.1	≥ 5.20	
Cortisol (pg/mg)	178.76	320.49	26.24 - 1744.30	≥ 143.62	
Low-density Lipoprotein (mmol/L)	2.53	0.83	0.88 - 4.59	≥ 3.05	
Parameters with low values showing possible risk (cut-off < 25% percentile)					
High-density Lipoprotein (mmol/L)	1.29	0.32	0.77 - 2.17	≤ 1.06	
Heart Rate Variability (ms)	45.94	20.96	12.9 - 120.2	≤ 32.80	

Table 14. Psychometric characteristics and allostatic load parameters along with threshold values (risk quartiles; n = 58). MS-PSS = Multi-dimensional Scale of Perceived Social Support; PSS-10 = Perceived Stress Scale, 10-item inventory; SOOS-14 = Sources of Occupational Stress, 14-item inventory; SSS-FF = Social Support Scale for Firefighters.

As expected, both psychosocial stress measures (PSS-10 and SOOS-14) were highly correlated (**Table 15**). As well, we observed a positive relationship between both stress measures and age, although neither association reached the threshold for statistical significance (PSS-10, age: *r* = .10, CI: -.16, .35, *p* = .44; SOOS-14, age: *r* = .23, CI: -.03, .46, *p* = .08). However, our analysis showed that the amount of time an individual served as a firefighter was significantly associated with work-related stress (SOOS-14; *r* = .35, CI: .10, .56, *p* = .01), but not with general-life stress (PSS-10; *r* = .12, CI: -.14, .37, *p* = .37).

We did not find a significant difference in levels of perceived stress between female and male firefighters; PSS-10 (female, M = 12.83, SD = 3.55 vs. male, M = 15.67, SD = 4.92; *t* [56] = 1.37, *p* = .18) and SOOS-14 (female, M = 5.50, SD = 3.51 vs. male, M = 6.31, SD = 4.38; *t* [56] = .44, *p* = .67). However, general levels of stress among participants who engaged in less than 10 minutes of physical activity over the past week (M = 18.71, SD = 6.50) were clearly greater than participants with a higher activity level (M = 14.92, SD = 4.47; *t* [56] = 1.99, *p* = .05). Similarly, for job-related stress, there was a significant difference (*t* [56] = 2.45, *p* = .046) observed between participants reporting less than 10 minutes of physical activity during the last week (M = 11.29, SD = 6.08) and those with more than this amount (M = 5.53, SD = 3.51). With regards to other health-related variables, both measures of stress (PSS-10 and SOOS-14) showed a positive, albeit not statistically significant, relationship with alcohol intake and sleeping behaviour.

	SOOS-14	PSS-10	SSS-FF	MS-PSS
SOOS-14		.56**	-.39**	-.27*
PSS-10	.56**		-.49**	-.31*
SSS-FF	-.39**	-.49**		.53**
MS-PSS	-.27*	-31*	.53**	

	Age	LOS	SBP	DBP	WHtR	HbA1c†	HDL	LDL	HRV†	HCC†
Age		.82**	.09	.27*	.23	.28*	-.02	.21	-.28*	.00
LOS	.82**		.05	.21	.13	.31*	.03	.11	-.21	-.00
SBP	.09	.05		.62**	.25	-.09	.08	.02	-.19	-.09
DBP	.27*	.21	.62**		.37**	.10	-.03	.25	-.33*	-.14
WHtR	.23	.13	.25*	.37**		.00	-.44**	.29*	-.12	.04
HbA1c†	.28*	.31*	-.09	.10	.00		-.00	.16	-.15	.06
HDL	-.02	.03	.08	-.03	-.44**	-.00		-.10	.16	-.14
LDL	.21	.11	.02	.25	.29*	.16	-.10		-.36**	-.14
HRV†	-.28*	-.21	-.19	-.33*	-.12	-.15	.16	-.36**		.16
HCC†	.00	-.00	-.09	-.14	.04	.06	-.14	-.14	.15	

Table 15. Bivariate comparisons between psychosocial stress and social support measures (*upper table*) and between age, LOS, and allostatic load parameters (*lower table*). DBP, diastolic blood pressure; HbA1c, glycosylated haemoglobin; HCC, hair cortisol concentration; HDL, high density lipoprotein; HRV, heart rate variability; LDL, low density lipoprotein; SBP, systolic blood pressure; WHtR, weight to height ratio. **Note**: † = log transformed, ** = p value < .01, * = p value < .05

7.4.3 Social Support in the Study Population

In our sample, the average MS-PSS score was 33.59 (SD = 4.15; **Table 14**); in addition, MS-PSS scores were not clearly correlated with either a participant's age (*r* = -.16, CI: -.40, .11, *p* = .25), or length of service (*r* = -.14, CI: -.39, .12, *p* = .28). Although female firefighters did report a greater perceived level of general social support than their male colleagues (M = 36.50, SD = 2.43 vs. M = 33.25, SD = 4.19), the difference was not quite enough to cross the threshold for statistical significance (*t* [56] = 1.85, *p* = .07). In addition, we observed a significant negative relationship between the MS-PSS and both psychosocial stress measures (**Table 15**).

With regards to work-related social support, the average SSS-FF score was 36.53 (SD = 5.01; **Table 14**). Like the pattern observed with the MS-PSS, female firefighters (M = 41.00, SD = 3.63) reported experiencing significantly more social support than their male counterparts (M = 36.02, SD = 3.63; *t* [56] = 2.40, *p* = .02); as well, SSS-FF scores did not seem to be affected by either a participant's age (*r* = -.17, CI: -.41, .09, *p* = .20), or LOS (*r* = -.16, CI: -.40, .10, *p* = .23). Notably, we observed a significant positive correlation between both social support measures (MS-PSS and SSS-FF), and significant negative correlations between the SSS-FF and both psychosocial stress measurements (**Table 15**).

7.4.4 Demographics, Biometrics, and Allostatic Load in the Study Population

The mean value of the ALI we measured within our sample of 58 firefighters was 1.90 (SD = 1.31, range = 0 – 5). Interestingly, despite modest proportions of our sample showing concerning levels of several individual parameters (particularly, systolic blood pressure and waist-to-height ratio; **Table 15**), nearly two-thirds of the participants displayed an ALI at a level of 2, or lower (**Figure 8**). Furthermore, bivariate analyses involving the physiological parameters used to form the ALI, age, and LOS were completed as part of our data exploration, and revealed a few interesting associations, including HDL and WHtR, HRV and LDL, and age with HRV (Table 3). Additional exploratory analyses on the individual ALI parameters and our psychosocial stress measures also revealed potentially notable associations between SOOS-14 and HbA1c (r = 27, CI: .02, .50, *p* = .03), SOOS-14 and HRV (r = -.32, CI: -.53, -.06, *p* = .02), and PSS-10 and DBP (r = .28, CI: .02, .50, *p* = .04).

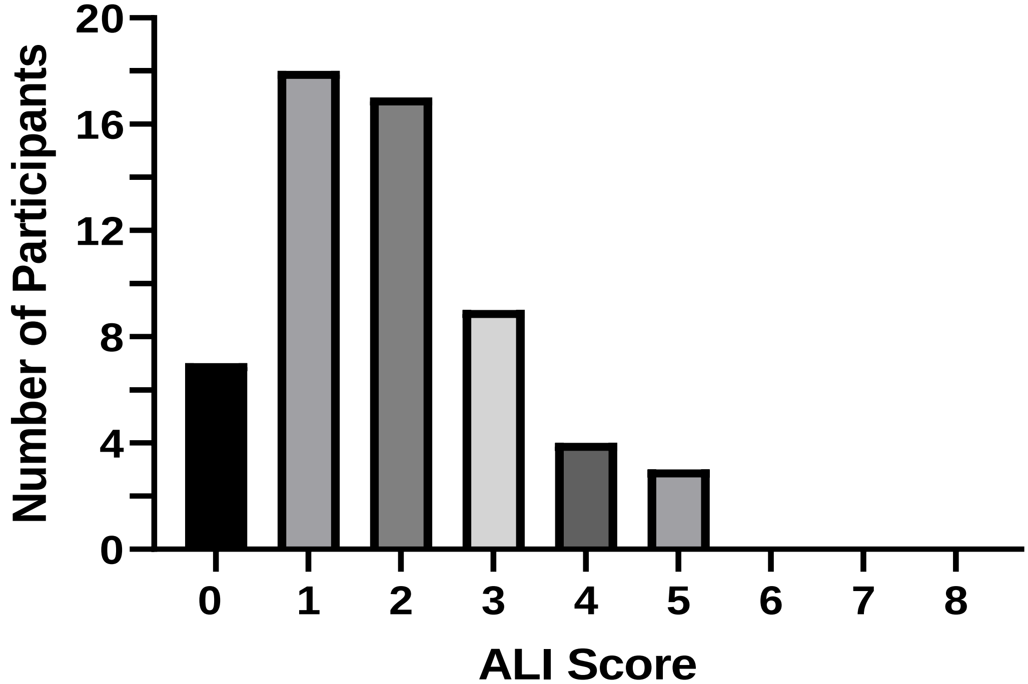


Figure 8. Frequency distribution of allostatic load index (ALI) scores (8 parameters; n = 58).

Considering the main demographic variables, we did not find an appreciable difference between male and female firefighters (**Table 16**); however, the ALI was clearly influenced by a participant's age (r = .27, 95% CI = .01, .50, p = .04). There was also a modest correlation between a participant's LOS and their ALI (r = .25, p = .06). Participants who reported engaging in fewer than 10 minutes of physical activity over the past week displayed an ALI about 40% greater than those with a higher activity level (**Table 16**). We also found that ALI scores declined as the reported sleeping time each night rose (**Table 16**). Although the differences observed across the various health-related variables moved in the expected direction, none reached statistical significance.

	ALI (Mean ± SD)		*t*	*p*
	Male	Female		
Gender	1.92 ± 1.33	1.67 ± 1.21	0.45	.65
	Yes	No		
Sports/Fitness Activity (> 10 min; past 7 days)	1.78 ± 1.29	2.71 ± 1.25	1.80	.08
	Yes	No		
Cigarette Smoking (past 30 days)	2.17 ± .983	1.87 ± 1.34	0.53	.60

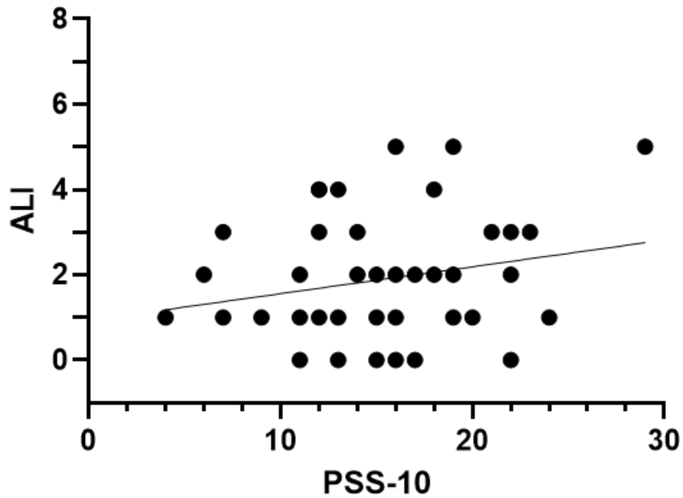
	ALI (Mean ± SD)			F	*p*
	0 - 3 x/month	1 – 3 x/week	> 3 x/week		
Alcohol Intake	1.56 ± 1.21	2.06 ± 1.41	1.88 ± .99	0.78	.46
	4 – 6 h	6 – 8 h	> 8 h		
Time Spent Sleeping Each Night	2.44 ± 1.13	1.81 ± 1.39	1.67 ± 0.82	0.97	.39
	Never	Sometimes	Most of the Time		
Frequency of Trouble Falling/Staying Asleep	1.69 ± 1.11	1.76 ± 1.37	2.55 ± 1.21	1.73	.19

Table 16. Comparison of allostatic load index (ALI) scores across key categorical variables (n = 58). Abbreviations: F, F statistic; p, probability value; SD, standard deviation; t, Student's t statistic.

7.4.5 Psychosocial Stress and Allostatic Load

When the predictor variables (SOOS-14 and PSS-10) were examined individually for an association with the ALI, we failed to observe significant correlations (SOOS-14: r = .19, CI: -.07, .43, p = .15; PSS-10: r = .23, CI: -.03, .46, p = .08; **Figure 9**). However, given the exploratory nature of our investigation, we proceeded with building our planned linear regression models to test whether perceived psychosocial stress would predict a participant's ALI. The first model combined both psychosocial stress measures, while the second and third models considered the potential confounding effects of age, LOS, and social support. All three models indicated that neither the PSS-10, nor the SOOS-14 could significantly predict ALI in our sample.

A)



B)

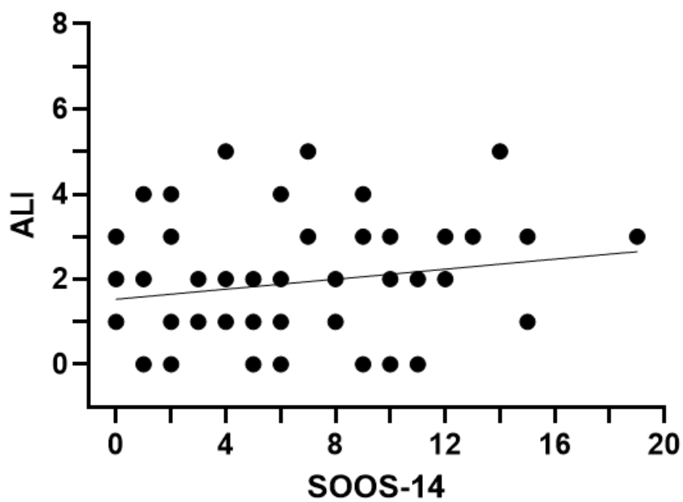


Figure 9. Scatterplots showing correlation of ALI with general (PSS-10; A) and work-related (SOOS-14; B) psychosocial stress (*n* = 58). Abbreviations: *r*, Pearson's correlation coefficient; ALI, allostatic load index; PSS-10, Perceived Stress Scale, 10-item inventory; SOOS-14, Sources of Occupational Stress scale, 14-item inventory.

The first model accounted for 6% of the total variance in the ALI (R^2 = .06, F[57]: 1.75, *p* = 0.18), while the second model accounted for 13% (R^2 = .13, F[57]: 1.97, *p* = .110), and the third model, 16% (R^2 = .16, F[57]: 1.67, *p* = .15). Finally, the final model consisting of all variables, and the interaction terms accounted for 20% of the total variance in the ALI (R^2 = .20, F [57]: 1.20, *p* = 0.31). We did not observe a notable degree of interaction between the putative moderating variables (MS-PSS and SSS-FF) and our predictor-outcome relationship (**Table 17**). Thus, when accounting for age and LOS, the ability of PSS-10 and SOOS-14 to predict the ALI did not change as a function of either MS-PSS, or SSS-FF. After considering all variables, only age was a significant predictor of ALI in the current sample of firefighters (*B* = .09, CI: .01, .17, *p* = .04).

		Regression Coefficient (B)				
Model	Predictor(s)	B	Standard Error	95% CI	t-statistic	p value
1	SOOS-14	.028	.048	[-.069, .124]	.574	.57
	PSS-10	.05	.04	[-.036, .134]	1.160	.25
2	SOOS-14	.022	.051	[-.079, .124]	.441	.66
	PSS-10	.047	.042	[-.037, .132]	1.124	.26
	LOS	-.034	.038	[-.110, .043]	-.884	.38
	Age	.067	.037	[-.007, .142]	1.806	.08
3	SOOS-14	.031	.051	[-.072, .134]	.600	.55
	PSS-10	.067	.045	[-.024, .157]	1.484	.14
	LOS	-.036	.038	[-.112, .041]	-.929	.36
	Age	.071	.037	[-.004, .146]	1.891	.06
	SSS-FF	.063	.043	[-.025, .150]	1.441	.16
	MS-PSS	-.030	.048	[-.126, .066]	-.618	.54

4	SOOS-14	-.251	.536	[-1.329, .827]	-.47	.64
	PSS-10	.485	.427	[-.374, 1.343]	1.14	.26
	LOS	-.047	.042	[-.131, .037]	-1.13	.27
	Age	.090	.042	[.006, .173]	2.16	.04
	SSS-FF	-.088	.162	[-.414, .238]	-.54	.59
	MS-PSS	.269	.212	[-.159, .696]	1.27	.21
	SOOS-14 * SSS-FF	-.002	.020	[-.042, .038]	1.10	.92
	SOOS-14 * MS-PSS	.010	.023	[-.036, .057]	.44	.66
	PSS-10 * SSS-FF	.008	.010	[-.011, .027]	.84	.41
	PSS-10 * MS-PSS	-.021	.015	[-.051, .008]	-1.44	.16

Table 17. Regression analysis examining the relationship between the outcome variable of interest (ALI) and the primary predictor variables (SOOS-14 & PSS-10), in the presence of confounding and moderating variables (*n* = 58). Abbreviations: CI, confidence interval; LOS, length of service; MS-PSS, Multi-dimensional Scale of Perceived Social Support; PSS-10, Perceived Stress Scale, 10-item inventory; SOOS-14, Sources of Occupational Stress scale, 14-item inventory; SSS-FF, Social Support Scale for Firefighters.

7.5 Discussions

Our exploratory study collected a range of demographic, behavioural, and physiological measures from a sample of firefighters serving a mid-sized urban region in Southern Ontario to broadly characterise a typical member of Canada's fire service. We also sought to make the first application (to the best of our knowledge) of the allostatic load concept to these workers to objectively appraise whether psychosocial stress might leave a physiological imprint on those within the fire service.

We observed a higher level of perceived general life stress in our group of firefighters than was found in an earlier report that also used the PSS-10 to examine participants from the fire service (J. S. Lee et al., 2014); notably, about three-quarters of our sample reported feeling nervous, or stressed at least some of the time. However, our participants did not seem to experience high levels of work-related stress, which is in contrast to some (Isaac & Buchanan, 2021; Stanley et al., 2018), but not all (Carpenter et al., 2015), previous work using the SOOS-14 with firefighters. Despite having a lower level of work-related stress than might have been expected, a few areas within the occupational environment of our participants did raise concern: poor diet, exposure to an overly demanding, or anxious co-worker, and perceived sleep disruption.

Although concern about having a poor diet was not highlighted as a key issue within an earlier report examining Canadian firefighters (Isaac & Buchanan, 2021), its appearance in our sample is an important observation, given that eating behaviour is consistently associated with adverse health outcomes (such as obesity and cardiovascular disorders) in both firefighters (Sotos-Prieto et al., 2017) and the general population (Wang et al., 2016). Indeed, poor dietary habits have often been observed amongst firefighters, and are thought to be attributable to several factors, including the typical fire station eating culture (high-caloric food intake, large portions, over-eating), together with sedentary work and night calls (Dobson et al., 2013; Sotos-Prieto et al., 2017). In our sample, the effect of poor diet was most visible in the average waist-to-height ratio, which was higher (M = 0.54) than the accepted sub-clinical threshold, 0.5 (Ashwell et al., 2012).

Not surprisingly, sleep disruption has been identified as an important stressor within the firefighting community (Carey et al., 2011); indeed, a recent Canadian study that examined a large group of firefighters using the SOOS-14 found sleep disturbances to be the primary source of stress (Isaac & Buchanan, 2021). Although the precise reason for impaired sleep quality may vary according to the jurisdiction studied, previous work has drawn attention to factors such as longer shifts and frequent emergency calls (Haddock et al., 2013; Yook, 2019). Regardless of its underlying cause, however, sleep disturbances can have a profound influence on the mental health of those in the fire service; for example, poor sleep quality has been associated with PTSD symptomology (Haslam & Mallon, 2003) and insomnia has been linked to clear elevations in risk for both anxiety and depression (MacDermid et al., 2021).

Along with identifying potential psychosocial stressors within the fire service, we also observed certain factors that appeared to influence the experience of these stressors. For example, we found that participants who engaged in regular physical activity each week reported lower work-related and general-life stress levels. Decades of research provide consistent support for the role that physical activity may play as a protective factor against psychosocial stress and its adverse health outcomes (Fondell et al., 2011; Hamer, 2012; Rimmele et al., 2007). As a result, physical fitness may not only be critical to performing duties related to fire suppression, but may also act as a counterbalance to psychosocial stress; indeed, physical activity may be partly responsible for the comparatively lower levels of work-related stress we observed in our sample.

Together with physical activity, we also identified social support from both family members and work colleagues as a variable that might offset the effects of psychosocial stress. High levels of perceived social support were observed across our participants, which seems to generally agree with what has been found recently in other larger-scale investigations of Canadian firefighters (Isaac & Buchanan, 2021; Vig et al., 2020). In particular, out of the various ways in which such support can take shape, one of the strongest was the feeling that they could discuss problems with their family members and talk to their colleagues about work-related experiences (interestingly, being able to talk with other firefighters about work-related experiences was also among the strongest examples of social support observed in other Canadian firefighters; Isaac & Buchanan, 2021). As well, despite not observing a strong association between a participant's perceived social support and their length of service, the relationship trend (an inverse one) was similar to that observed in other studies, with significant findings between both variables (Regehr, 2009; Regehr et al., 2003).

Among the variables that we examined for an effect on allostatic load, only a firefighter's age stood out in a statistically significant manner. Our finding that allostatic load increased with age agrees with the notion of allostatic load reflecting accumulated “wear-and-tear” (Crimmins et al., 2003; Seeman et al., 2001), and is consistent with observations made in other occupational groups (Schnorpfeil et al., 2003; J. Sun et al., 2007). Aside from the expected influence of age, workplace factors inherent to firefighting may also contribute to the way in which allostatic load builds up within these workers. Typically, fire departments recruit young, physically fit, and enthusiastic candidates and these characteristics may help buffer many of the stressors linked to firefighting (Makara-Studzińska et al., 2020; Regehr et al., 2003). However, as firefighters age, acquire more responsibilities, and experience workplace stressors (for example, increased job demands, shift work, and inter-personal conflict; Igboanugo et al., 2021), they may become increasingly susceptible to the sort of physiological changes captured by allostatic load (Makara-Studzińska et al., 2020; Murphy et al., 2002).

Although our analysis of psychosocial stress and allostatic load in firefighters did not reveal a statistically significant relationship, we did find that both general and work-related stressors displayed a positive association with allostatic load. Notably, the pattern we observed agrees with that seen in several studies involving larger groups from other occupations. For example, Bellingrath et al. (2009) investigated female school teachers, while Mauss, Jarczok, & Fischer (2015) and Sun et al. (2007) investigated industrial workers. All three studies employed allostatic load assessment to capture the physiological imprint of work-related stress (strain, exhaustion, and demands) and consistently found a strong positive relationship between work-related stress and allostatic load.

7.5.1 Limitations

Despite the contributions that we feel have been made by our work, important limitations should be acknowledged when considering the results. First, our sample was modest in size despite our best recruitment efforts (and the apparent enthusiasm for the study at both the administrative and union levels). The size limitation may have prevented us from arriving at the required level of statistical power needed to observe clear patterns between our variables of interest. Second, as with all cross-sectional studies, causal and directional claims among the main variables cannot be inferred. Hence, there is a need for a longitudinal study that will permit the examination of the directionality and temporality of the observed associations. Third, our sample was comprised primarily of healthy (low level of health-risk behaviours) male, middle-aged firefighters of European descent. The homogeneity of our sample could limit the generalisability of our results; however, the external validity of our findings remains unclear, given that there are currently no national-level data regarding the demographic characteristics of those in the Canadian fire service. A more diverse sample may be required to capture the changing demographics within firefighting adequately; this is especially important to urban centres that may see a workforce more heterogeneous (with regards to various factors) than the one captured in the current report.

Fourth, given that the extent and robustness of the relationship between work-related stress and allostatic load may differ by biological sex and gender (Juster et al., 2013; Mair et al., 2011), bivariate and regression analyses should be stratified along these lines; however, with the limited number of female participants in our study, this analysis could not be done. Furthermore, we relied on self-reported measures to assess psychosocial stress and social support; as a result, our instruments may have been affected by recall bias, or response bias (either under, or over-reporting). Finally, since psychosocial stressors and their embedding were the primary focus of this study, we did not consider the potential effect of physical and/or traumatic stressors. Given that physical and traumatic stressors can impact firefighter health to varying degrees, we may have missed a significant influencing factor on our sample's AL. Including measures capturing physical and traumatic stressors when investigating AL will provide a more nuanced picture of the cumulative physiological consequences of stress experiences among firefighters.

7.6 Conclusions

Although the association between psychosocial stress and allostatic load in our sample of firefighters moved in the expected direction, the relationship was not statistically significant (likely, due to our modest sample size); however, age did emerge as an important variable to consider. Further, we observed interesting correlations between work-related stress and perceived social support; however, in our regression modelling, social support failed to moderate the relationship between psychosocial stress and allostatic load.

Emerging from our exploratory analyses, we believe certain suggestions can be made to support firefighter health. In particular, the observed influence of age suggests that psychosocial stressors in firefighters should be addressed to reduce physiological "wear and tear" and ensure healthy ageing. As well, health-promotion interventions, such as allocating time for physical activity, effective sleep hygiene, and nutrition education programmes, should be prioritised to address some of the factors that appear to be sources of work-related stress among firefighters. In addition, team cohesion activities, such as inter-platoon or inter-station events, may help foster communication and community-building amongst firefighters, thereby building trust, alleviating stress, and providing additional coping resources.

Although our study has allowed us to comment more on informative trends than definitive relationships, we firmly believe that the allostatic load framework remains a useful tool to investigate psychosocial factors that may influence firefighter health over the long term. Indeed, despite the limitations that flowed from working with a modestly sized and largely homogeneous sample of firefighters, we are confident that a more robust sample size would have allowed us to observe stronger relationships between our study variables.

Chapter 8

AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN PSYCHOSOCIAL STRESS AND ALLOSTATIC LOAD IN A SAMPLE OF CANADIAN FIREFIGHTERS DURING THE COVID-19 PANDEMIC

8.1 Abstract

Background: Psychosocial stress has been shown to adversely impact the health and wellbeing of firefighters, leading to grave implications for public safety. Allostatic load (AL), a multi-system indicator of physiological wear and tear, may explain the mechanism leading from psychosocial stress to adverse health outcomes.

Objectives: This longitudinal study aimed to investigate psychosocial stress experience in a sample of firefighters and its association with the AL index developed using biomarkers from the cardiovascular, metabolic, and neuroendocrine systems.

Design: A longitudinal study using 2 phases of data collection.

Methods: The study was initiated with 63 active firefighters; however, the final sample consisted of 46 participants who completed both data collection phases. A range of demographic, stress and social support measures were taken. An index of physiological biomarkers was also collected in both phases. Data analyses were completed using descriptive statistics, bivariate analysis and mixed-effects modelling. The linear mixed-effects model was fitted to model the change in AL across both phases and determine its association with psychosocial stress after accounting for confounding factors (Covid-related stress, demographic factors, and psychosocial resources)

Results: Our findings revealed that general life psychosocial stress at baseline predicted AL over time after accounting for firefighters' age, perceived psychosocial support, and Covid-19-related stress. Interestingly, our findings failed to support an association between work-related psychosocial stress and AL. Incidental findings include a high prevalence of Covid-19-related stress and an abundance of perceived social support.

Conclusion

Daily life stressors outside the workplace significantly impact firefighters' AL trajectory. Therefore, a more holistic approach to health promotion should be considered to address psychosocial stress within the fire service.

Keywords: Psychosocial stress, Allostatic load, Covid-19, social support, work-related

8.2 Introduction

Firefighting consistently ranks amongst the top five most stressful jobs in North America (Min, 2019). Along with fire suppression, firefighters often attend to many emergencies, including hazardous material spills, large-scale community disasters, and medical emergencies (DeJoy et al., 2017; Vock, 2018). Not only do firefighters have to put out fires and perform similar work-related duties, but they must also manage less obvious psychosocial work demands such as rotating shift work (Bongkyoo Choi, Schnall, et al., 2016; Haddock et al., 2013), interpersonal/organizational conflict (Jang et al., 2016, 2017), and an exhausting organizational system (M. G. Kim et al., 2013; Lim et al., 2014). As a result, firefighters may experience significant strain attributable to psychosocial stressors, in addition to the physical risks associated with their profession.

In the last two decades, psychosocial stressors in the workplace have garnered growing interest owing to compelling evidence pointing to a significant association between this type of stress and adverse health outcomes, including chronic disease development and progression (Ganster & Rosen, 2013; Juster et al., 2010; O’Connor et al., 2021). This unique type of work-related stressor emerges from poorly designed work organization, structure, management, and poor social work culture and conditions, and may cause physical and psychological strain (Cox & Griffith, 1995).

Aside from the impact of work-related psychosocial stress on firefighters’ daily job performance and productivity, its effects may also spill into other aspects of their lives, including relationships outside work and family life. In particular, the “spillover” effect from work-related stress may impact work-family balance, leading to conflict or parental stress (Shreffler et al., 2011). Further, firefighters may experience a more significant risk of a wide range of somatic, mental, and behavioural health changes, given their likelihood of experiencing psychosocial stress and its potential amplification by the organizational culture and structure of the urban fire service (Beaton et al., 1995; Fisher & Etches, 2003; Igboanugo et al., 2021). Hence, not only do psychosocial stressors impact firefighter health and well-being, these challenges may have broader public implications. For example, these challenges may manifest as increased rates of absenteeism, sick days, long-term disability, increased turnovers, early retirements, and increased healthcare spending (Fisher & Etches, 2003; Gadinger et al., 2012).

Despite the compelling evidence depicting psychosocial stress as a significant workplace hazard, different views on its measurement and the mechanism whereby its experience may impact worker health exist. Since most of the current evidence relating to stress perception and assessment amongst firefighters has relied on the subjective measurement of stress (e.g., self-report questionnaires, interviews), questions still linger regarding how psychosocial stressors may leave a physiological imprint. In addition, a considerable number of studies have focused on firefighters’ health outcomes (Igboanugo et al., 2021); however, to our knowledge, none have investigated the underlying pathway connecting psychosocial stressors and physiological dysregulation in firefighters over time.

Over the past three decades, input from several fields has contributed to development of the allostatic load model, an objective assessment of the physiological burden imposed by stressors upon the body (McEwen, 1998). By combining several of the classical stress-response ideas of Selye's work with the more recently developed appreciation for the importance of cognitive appraisal, allostatic load attempts to measure the cumulative effect of the body's efforts at adapting to stressful stimuli by investigating multiple physiological changes (McEwen & Stellar, 1993, McEwen, 2007). Simply put, the continuous need to respond to environmental challenges comes with a cost in the form of changes across a variety of areas (mainly in the cardiovascular, metabolic, neuroendocrine, and immune systems) that can gradually increase the risk for both disease and mortality (Guidi et al., 2021; Juster et al., 2010; Seeman et al., 1997).

Several observational studies have provided evidence linking repeated exposure to work-related psychosocial stressors with high allostatic load (Bellingrath et al., 2009; Mauss et al., 2016; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003; J. Sun et al., 2007). Similarly, there is a reasonable likelihood that the same situation may occur with firefighters, in that these unique stressors not only "get under their skin" in a fashion that increases the risk for disease, but may also lead to behavioural issues with health consequences, such as problematic alcohol use (Hosoda et al., 2012; Lupien et al., 2018).

Further complicating the work environment of firefighters was COVID-19, a highly communicable viral disease that emerged in 2019 from a novel type of Coronavirus in humans

(SARS-CoV-2). The COVID-19 pandemic continues to impact the health and livelihood of individuals worldwide, especially in Canada (Best et al., 2021; Coulombe et al., 2020). Essential workers bore a significant burden because they were expected to perform their duties regardless of the risks involved, especially at the pandemic's start. Since firefighters were deemed "essential", they were also not spared from the impact of the novel virus pandemic. In addition to the risk of being exposed to (or actually contracting) the COVID-19 virus, firefighters also experienced elevated risk of stress from associated psychosocial factors, including limited interpersonal contact, increased job demands/insecurity, and work-family conflict (Coulombe et al., 2020; Lima et al., 2020). Taken together, these stressors may have significantly contributed to allostatic load build-up within this professional group, thereby increasing their susceptibility to stress-related diseases and COVID-19.

Research has shown that the availability of the psychosocial resource found in social support may boost resilience amongst firefighters since it creates a welcoming work environment and fosters camaraderie within the group (Beaton & Murphy, 1993; Regehr, 2009; Regehr et al., 2003). In addition, social support directly, or indirectly (i.e., as a stress-buffering mechanism) influences physiological dysregulation emanating from the allostatic load (Cohen, 2004). Thus, a lack of social support may contribute to the accumulation of allostatic load in firefighters, making it necessary to inquire how social support might attenuate a firefighter's stress experience and influence their AL.

Furthermore, certain demographic factors may impact the sequence of events from perceived psychosocial stress to allostatic load. For example, a firefighter's age and years devoted to the profession may be critical determinants of allostatic load development. There is strong evidence linking age as a significant predictor of allostatic load within the working and general population (Crimmins et al., 2003; Seeman et al., 2001). Such a relationship is expected since the multi-systemic physiological changes observed within the allostatic load index reflect the cumulative change in the body's function over the lifespan (Guidi et al., 2021); hence, as individuals age and their physiological systems lose functioning and adaptability wanes, AL increases (Crimmins et al., 2003). In addition, because firefighters devote a significant portion of their lives to their service, stress exposures inherent to their job may contribute to allostatic load development (Goh et al., 2020; Negm et al., 2017).

Despite the growing concern associated with psychosocial stress within research and public health domains, inquiry into the cumulative effect of these unique stressors and how they may lead to bodily wear and tear (AL) is still lacking. In particular, we believe that no attempt has been made to investigate the link between psychosocial stress experience and AL over time in firefighters. Furthermore, studies involving firefighters that investigated the effect of the COVID-19 pandemic on health and day-to-day activities have mainly focused on the incidence/prevalence of infection (G. A. Durand et al., 2021; McGuire et al., 2021), health-related outcomes (Lima et al., 2020), and vaccine uptake (Caban-Martinez et al., 2021). Hence, there is a paucity of research on the effects of psychosocial stress brought about by the Covid-19 pandemic amongst firefighters.

To address the existing knowledge gap, we investigated psychosocial stressors unique to Canadian firefighters' lives and working environments and examined if they prospectively predict AL while accounting for potential confounding factors such as age and the availability of social support. In addition, we examined the prevalence of Covid-related stress within this group and its effect on perceived psychosocial stress and allostatic load. Based on previous empirical findings on the stress-allostatic load relationship in other investigated working populations, we predicted that high perceived psychosocial and covid-related stress would be associated with higher AL at follow-up.

8.3 Materials and Methods

8.3.1 Study Population

Firefighters were recruited from Waterloo Fire Rescue, which serves the City of Waterloo, Ontario. Eligibility for participation in this study required active service at the time of data collection. No exclusion criteria for medical history, or medication use were applied; however, these data were collected and considered during data analysis. The office of Research Ethics at the University of Waterloo granted ethics approval for this study.

The study consisted of two phases of data collection. At both phases of data collection, a standardized protocol was utilized that included participants providing informed consent, completing a set of questionnaires, and permitting the collection of physiological measurements by trained investigators. During both phases of data collection (first phase: October 2019 – January 2020 and second phase: November 2020 – January 2021), data were collected on weekdays between 9:00 am and 12:00 noon and always took place during a participant's first shift following two days away from work.

In the first phase of data collection, the total sample consisted of 57 men (90%) and 6 women (10%) with a mean age of 41 years (SD = 7.9 years, range 27 - 58 years); notably, one participant had substantial missing questionnaire data and was excluded from further analyses. During the follow-up data collection (phase 2), 13 participants did not participate due to conflicting schedules, retirements, or vacations, leaving 51 firefighters with an average age of 41 years (SD = 7.7 years, range 28 – 58 years). All 13 participants lost to attrition were men, and were mostly older firefighters with an average age of 47 years (SD = 7.08 years) and a career length of about 17-years.

8.3.2 Questionnaire-based Measurements

During data collection, questionnaires were administered at baseline and follow-up in a standardized fashion to collect information on three topics: general demographic and health characteristics, perceptions of social support from family, friends, and work colleagues, and impressions of work and general life stress. The baseline demographic questionnaire captured each participant's age, gender, ethnicity, primary language, level of education, relationship status, rank, and length of service as a firefighter. The general health survey, modelled on the Canadian Community Health Survey, broadly assessed a participant's medical history (e.g., presence of hypertension) and health risk behaviours (e.g., alcohol use and level of physical activity) and was administered during the first phase.

Prior to the second phase of data collection, public health measures, including travel restrictions, compulsory remote work, limitation of gatherings, and mandatory quarantine/self-isolation, were enacted to limit the spread of the disease. Hence, three relevant questions were administered during the second data collection phase to assess stress-related experiences due to the COVID-19 pandemic and restrictions. For example, information regarding exposure to COVID-19 and stress brought upon by Covid-related changes in their private lives was collected.

Appraisal of Psychosocial Stress.

Both measures used to investigate psychosocial stress within our sample were taken at baseline; they include the Sources of Occupational Stress scale (SOOS-14, an occupation-specific tool) and the Perceived Stress Scale (PSS-10, which assesses perceived general life stress). The SOOS-14 (Kimbrel et al., 2011) is a 14-item revised version of Beaton and Murphy's (1993) Sources of Occupational Stress scale. The SOOS-14 measures psychosocial stressors specific to firefighters (e.g., conflict with colleagues, financial strain, and feelings of isolation from family due to work demands). The questions ask participants to consider how bothered they have felt by these stressors over the past ten shifts (given their schedule format, ten shifts would typically take place over about three weeks). For our study, items were scored on a 3-point Likert scale (0 = not at all bothered; 1 = somewhat bothered; 2 = extremely bothered), which allowed a range from 0 to 28. Higher scores indicate higher perceived stress levels. In addition, the SOOS-14 questionnaire has exhibited good internal consistency (α =

.86), and good validity coefficients across independent samples of firefighters (Carpenter et al., 2015; Kimbrel et al., 2011). For this study, we recorded a Cronbach alpha of .81.

The PSS-10 (Cohen & Williamson, 1988) is a widely used instrument for appraising the perception of general life stress over the past month and is scored on a 5-point Likert scale ranging from 0 (never) to 4 (very often). The PSS-10 scores are obtained by reversing responses to the four positively stated items (items 4, 5, 7, and 8) and then summing across all scale items. Individual scores on the PSS-10 can range from 0 to 40, with higher scores indicating greater perceived stress. Previous work has revealed that the PSS-10 shows good reliability with a Cronbach's alpha of $\alpha = .78$ (Cohen & Williamson, 1988); an alpha of .80 was calculated for this study.

Measure of Social Support

The Firefighter Social Support Scale (SSS-FF; Carpenter et al., 2015) was used to assess the level of social support perceived by the participants in the first phase. The SSS-FF contains 9-items that measure the level of social support firefighters feel they have received from colleagues over the past six months. The scale uses a 5-point Likert-based scoring system, and responses range from "strongly disagree" to "strongly agree". The SSS-FF score is obtained by reversing the response to question 3 and then summing across all scale items, with higher scores indicating a higher degree of perceived social support. Previous work has recorded a Cronbach's alpha of .81 for the SSS-FF (Carpenter et al., 2015) and for this study, we recorded an alpha of .83.

8.3.3 Physiological Measurements

In order to quantify the cumulative wear and tear (AL) from psychosocial stress, several physiological indicators representing vital physiological responses from cardiovascular, neuroendocrine, metabolic, and immune systems are aggregated to derive an allostatic load index (ALI Seeman et al., 1997). The AL biomarkers retrieved for this study were from three primary physiological systems. First, indicators from the neuroendocrine system included hair cortisol level and heart rate variability (HRV). Second, indicators from the cardiovascular system included diastolic blood pressure (DBP) and systolic blood pressure (SBP). Third, indicators of general metabolic function included waist-to-height-ratio (WHtR), glycosylated haemoglobin (HbA1c), low-density lipoprotein (LDL), and high-density lipoprotein (HDL). The parameters chosen to determine the ALI were based on supporting literature (Juster et al., 2010; Seeman et al., 2001). The biomarkers were collected during a morning (8:00 am – 12:00 pm) visit to the allocated research data collection center during each data collection phase. In addition, participants were advised to abstain from alcohol and heavy meals in the evening prior to data collection. They were also asked to avoid caffeine and intense physical activity on the morning of data collection.

Blood pressure (SBP and DBP) was measured twice, with the participant in a relaxed and seated position, once at the start of a meeting and then again at the end, using an automated OMRON 3 Series upper arm blood pressure monitor. Height was measured with a free-standing stadiometer, and waist circumference (WC; in centimetres) was measured horizontally at the midway point along the smallest circumference between the lowest ribs and iliac crest. A simple division of the WC over height was performed to determine the WHtR.

Blood samples for lipid (HDL and LDL) and HbA1C analysis were collected with a finger-prick blood draw using a 2.2 mm lancet. For lipid measurement, a portion of the collected blood sample (15 - 40 μL) was placed on a test strip and inserted into a CardioChek PA analyser (PTS Diagnostic, Sunnyvale, USA). For HbA1c measurement, blood samples (5 μL) were placed on a test strip and inserted into the A1CNow+ analyser (PTS Diagnostic, Sunnyvale, USA).

Heart rate variability was recorded using the Bittium Faros ECG Ambulatory Sensor (Bittium Corporation, Finland) with an ECG sampling frequency of 1000 Hz. With participants relaxed in a seated position, the sites intended for electrode placement in the chest region were prepared with NuPrep and alcohol, with the shaving of chest hair done as needed. Snap-on electrodes were placed firmly on three sites in the chest area (one electrode on each side beneath the midpoint of the clavicle and one on the left fifth intercostal space at the mid-clavicular line). Signals from the Bittium Faros device were interpreted using the Cardiscope Analytic software (Smart Medical, UK); primarily, the root-mean-square differences of successive R-R intervals (RMSSD) were used.

We determined the hair cortisol concentration (HCC) by retrieving hair samples (about 10 g) from the vertex of the scalp, with a focus on approximately the first 3 cm of the hair shaft. Each sample was taped to a collection card indicating the root end and then sealed in a labelled envelope with the participant's identification code before being sent for analysis at the Drug Safety Laboratory at Western University. A detailed description of the method used for cortisol extraction and analysis has been described by Gow et al. (2011).

Computing the AL Index Score

To derive the ALI, a summary score of physiological biomarkers was computed based on parameters scoring in the highest quartile (75^{th} percentile) of risk for the total population under study (except for HDL and HRV, where risk was defined as scores within the lowest quartile; that is, the 25^{th} percentile) as established by Seeman et al. (1997). Hence, values falling within the high-risk threshold were scored as "1", while other values were scored as "0", and scores ranged from 0 to 8, with higher scores representing elevated allostatic load.

8.3.4 Statistical Analyses[5]

We performed all statistical analyses using the SPSS statistical software for Windows (version 28.0.1.0; IBM SPSS, 2021) and R Studio for Windows (version 2022.02.2+485; RStudio Inc, 2022). Prior to hypothesis testing, the data were examined for distributional characteristics using the D'Agostino-Pearson's test and skewed variables (HbA1c, HCC, and HRV) were log-transformed. We observed a similar pattern of results using both transformed and non-transformed data; hence, we presented our findings in their original form (non-transformed).

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[5] The SPSS syntax and R code are available in **appendix O**

For descriptive analyses, means and standard deviations (SD) were calculated for continuous variables, while frequency (*n*) and percentages were determined for categorical variables. Bivariate analyses, including Pearson's correlations (continuous variables) and independent Student's t-testing (categorical variables), were used to investigate associations between variables across both time waves. Specifically, Pearson's correlation coefficient investigated associations between baseline demographic variables such as age and length of service (LOS) and the ALI score. Independent Student's t-tests were used to compare mean ALI differences between 2-item categorical variables (sex, marijuana consumption, and Covid-related stress). All but 2 participants identified as White/European; hence, ethnicity was not considered. In addition, one-factor analysis of variance (ANOVA) was used to compare the mean ALI across three or more item categorical variables (alcohol intake, education level, rank, relationship status, and time spent sleeping each night).

We performed linear mixed-effect modelling (fixed and random effects) using the "nlme" package in R-software. This analytical method permits the investigation of AL within firefighters while accounting for variability within and across participants (V. A. Brown, 2021). Advantages of this method include utilising all outcome data through the follow-up phase, handling missing data, managing data from unevenly spaced observations, and capturing correlated data from repeated measures using "random effects" that describes cluster-specific trends over time (Garcia & Marder, 2017; Schober & Vetter, 2018).

First, we fitted the unconditional mean and growth models with subjects and their intercept and slope as random effects. The intercept represents the subject's baseline initial status (or level). In greater detail, Upchurch et al. (2015) describe the intercept as a constant for the subject across times and reflect the information regarding the mean of the collective individual intercepts that represent each subject's AL growth curve with time. Further, the slope corresponds to the rate of change in AL over the study's period (Upchurch, Stein, et al., 2015). These models offer an opportunity to partition the variance estimates at all levels expressed as the intraclass correlation coefficient (ICC)[6], allowing us to account for individual variation in the AL across the subjects and time (Singer & Willet, 2003). We then ran a conditional growth model, where we tested the main effects of psychosocial stress (general-life and work-related stress) on the AL level and its change with time (AL slope; Model 1). Next, model 2 included the predictors in model 1 and accounted for the role of age and perceived social support at baseline. Finally, model 3 combined the Covid-19-related stress variable and the investigated variables in model 2 to test the role of Covid-19-related stress on the association between psychosocial stress experience and AL across time. We used the maximum likelihood (ML) as the primary estimator since our primary interest was in the "fixed effects" of the predictors on AL across time (Korner-Nievergelt et al., 2015).

[6] Higher ICC values indicate significant clustering in the level 2 variable; hence, a multilevel modelling recommendation.

8.4 Results

8.4.1 General Characteristics of the Study Population

As presented in **Table 18**, between the 63 participants in the first phase and the 51 returning participants in the follow-up phase, only 46 provided complete data in both phases of data collection. Of the 46 participants, 40 were men (87%) and 6 women (13%) with a mean age of 40 years (SD = 7.8 years, range 28 – 58 years). On average, study participants had been with Waterloo Fire Rescue for 13 years (SD = 7.5 years, range 1.3 - 33 years), were mostly married, or in common-law relationships (93.5%), were college-educated, and described their ethnic background as White/European (96%).

Regarding health-related behaviours (**Table 18**), 46% reported consuming alcohol 4-6 times a week, while a few used cigarettes in the last month (8.7%); however, marijuana use was more common (28.3%). In addition, most participants (45.7%) engaged in sports-like activities for 2.5 – 5 hours weekly. As for sleeping-related activity, most firefighters (80%) in our sample reported sleeping six, or more hours each night. However, most participants (70%) had trouble falling, or staying asleep at least some of the time.

		Number (%)	Mean ± SD
Age (years)			40.46 ± 7.8
Gender			
	male	40 (87)	
	female	6 (13)	
Ethnicity			
	White/European	44 (95.7)	
	all others	2 (4.3)	
Length of Service (years)			12.9 ± 7.5
	0 – 10	17 (37)	
	11 – 20	20 (43.5)	
	21+	9 (19.6)	
Rank			
	Firefighter	32 (69.6)	
	Captain	10 (21.7)	
	Platoon Chief	4 (8.7)	
Education			
	High school diploma	4 (8.7)	
	College degree	31 (67.4)	
	University degree	9 (19.6)	
	Post-graduate degree	2 (4.3)	
Relationship status			
	Single	2 (4.3)	
	Married/Common law	43 (93.5)	
	Divorced	1 (2.2)	
Smoking			
	Yes	4 (8.7)	
	No	42 (91.3)	
Marijuana consumption			
	Yes	13 (28.3)	
	No	33(71.7)	
Alcohol Intake			
	Never	2 (4.3)	
	≤3 times a month	5 (10.9)	

		Number (%)	Mean ± SD
	Once a week	10 (21.7)	
	2-3 times a week	8 (17.4)	
	4-6 times a week	21 (45.7)	
	Daily	0 (0.0)	
Sports/Fitness Frequency			
	<2.5 h	9 (19.6)	
	2.5 – 5 h	21 (45.7)	
	>5 h	16 (34.8	
Sleeping Patterns			
Amount of time spent sleeping each night.	4-6 h	9 (19.6)	
	6-8 h	32 (69.6)	
	>8 h	5 (10.9)	
Frequency of trouble falling/staying asleep.	Never	14 (30.4)	
	Sometimes	28 (60.9)	
	Most of the time	4 (8.7)	

Table 18. Summary statistics for study participants' demographic characteristics and health behaviours for firefighters participating in both phases (n = 46). SD, standard deviation; h, hours.

8.4.2 Psychosocial and Covid-19 Stress in the Study Population

As for perceived general life stress, our sample's average baseline PSS-10 score was 15.52 (SD = 4.75). Again, specific stressors stood out; 76% of participants indicated they felt nervous and "stressed" at least some of the time, while 72% sometimes felt angered by things outside their control, and 70% felt upset from unexpected happenings. Further, when measuring the magnitude and nature of work-related psychosocial stress among the participants, we observed an average baseline SOOS-14 score of 6.13 (SD = 4.31); notably, unlike other versions of the SOOS-14, ours allowed for a maximum score of 42. Among psychosocial work-related stressors impacting our participants, concerns about disrupted sleep, having a poor diet, and exposure to an overly demanding, or anxious co-worker were the most reported. Both baseline psychosocial stress measures, i.e., PSS-10 and SOOS-14, were significantly correlated, as expected ($r = .57$, $p < .001$).

Firefighters experiencing a high level of work-related stress captured by the SOOS-14 at baseline were older ($r = .32$, CI: .03, .56, $p = .03$) and longer serving ($r = .48$, CI: .22, .68, $p < .001$); although female firefighters reported lower levels of perceived stress on both measures, the recorded difference was not significant (PSS-10, $t\,[44] = 1.5$, $p = .14$; and SOOS-14, $t\,[44] = .38$, $p = .70$). There was a significant increase in perceived work-related stress (F [45] = 5.93, $p = .005$) as firefighters advanced through their professional hierarchy; that is, firefighters (mean = 5.03, SD = 3.41), captains (mean = 7.40, SD = 4.12), and platoon chiefs (mean = 11.75, SD = 6.90). Although a similar trend was observed with general-life stress experience, it did not meet the significance threshold (F [45] = .04, $p = .97$). Lastly, both measures of stress (PSS-10 and SOOS-14) displayed a non-statistically significant relationship with alcohol consumption, smoking, marijuana use, sleep amount, and physical activity.

Stress attributable to the COVID-19 pandemic was recorded at follow-up. Among the participants, 48% of the sample felt that the COVID-19 pandemic had been a significant source of stress. Further, due to known and unknown exposure to COVID-19, 17% of the sample had to self-isolate for at least fourteen days, while 15% reported that a person close to them, including family members, had become sick from COVID-19. The group of firefighters (48%) who reported stress attributable to the COVID-19 pandemic at follow-up recorded higher work-related stress at baseline (mean = 7.36, SD = 5.10) than their counterparts who did not report stress related to the pandemic (mean = 5.00, SD = 7.36); the difference between both groups with regards to work-related stress was marginally significant (t [44] = 1.87, p = .07). Similarly, firefighters experiencing COVID-19-related stress reported higher general-life stress compared to those that reported no stress from COVID-19; however, the difference was negligible (t [44] = 1.15, p = .26).

8.4.3 Social Support in the Study Population

Regarding work-related social support, the average baseline SSS-FF score was 36.61 (SD = 4.97). When considering social support across gender, female firefighters (M = 41.00, SD = 3.63) reported experiencing significantly more social support than their male counterparts (M = 35.95, SD = 4.84; t [44] = 2.44, p = .02). In addition, the SSS-FF score was not significantly impacted by either a participant's age (phase 1, r = -.16, CI: -.43, .14, p = .28), or

LOS (phase 1, r = -.13, CI: -.40, .17, p = .40). We observed significant negative correlations between the SSS-FF and both psychosocial stress measurements at baseline (SOOS-14, r = .35, CI: -.58, -.07, p = .02 and PSS-10, r = -.39, CI: -.61, -.12, p =.007). When considering Covid-19-related stress, there was no significant difference in perceived social support between individuals reporting covid-19 stress versus those who did not (t [44] = .22, p = .82).

8.4.4 Demographics, Biometrics, and Allostatic Load in the Study Population

The mean scores of the ALI recorded from our sample of 46 firefighters at both phases were: phase 1, 1.83 (SD = 1.38, range = 0 – 5) and phase 2, 1.74 (SD = 1.60, range = 0 – 7), (Figure 10). In addition, we did observe notable cortisol levels in both phases (i.e., they recorded mean values above the 75^{th} percentile; Table 19); however, the mean difference in change from the first phase to the second was borderline significant (t [45] = 1.90, p = .06) with a small effect size (Cohen's d = .3). Exploratory bivariate analyses of physiological biomarkers constituting the ALI in both phases revealed a few interesting relationships. Of all the relationships observed, only significant associations between WHtR and HDL and WHtR and LDL occurred in both phases (**Table 20**).

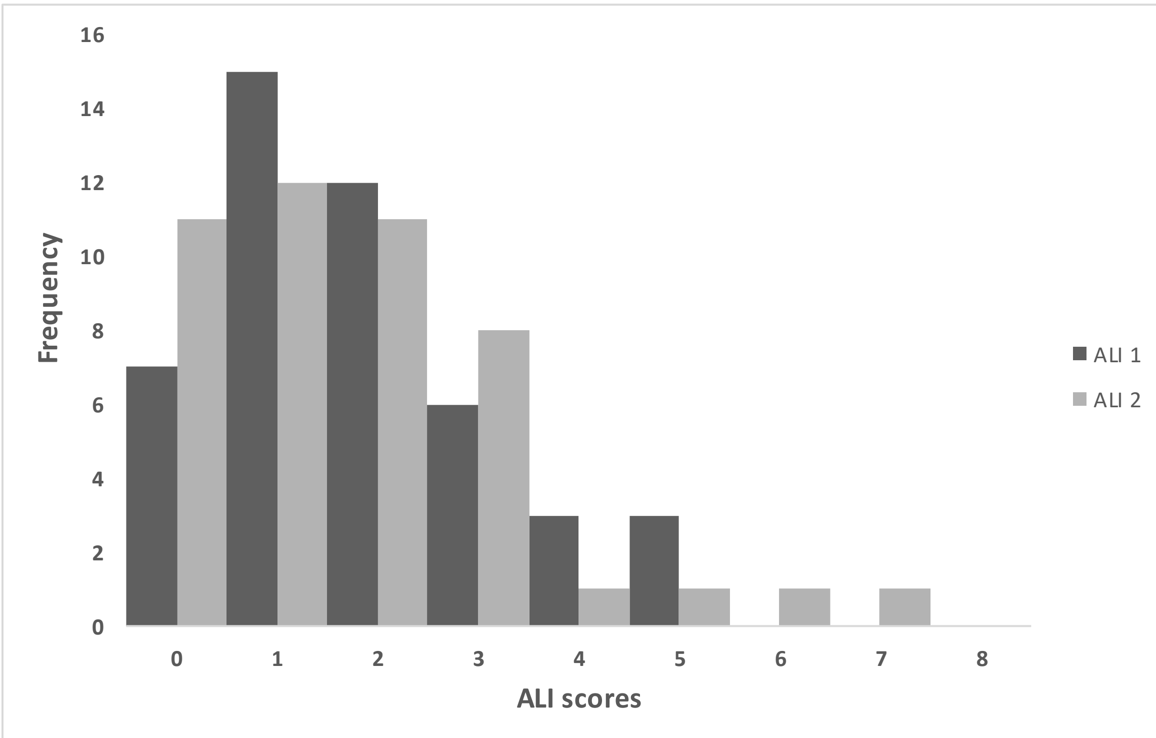

Figure 10. Frequency distribution of AL in phases1 and 2 (*n* = 46)

Biomarker	Phase 1			Phase 2			Statistical cut-off value (risk quartile) at baseline	Statistical cut-off value (risk quartile) at follow-up
	Mean	SD	Range	Mean	SD	Range		
Systolic blood pressure (mmHg)	134.40	12.06	111.0 – 170.0	135.40	11.76	113.0 – 164.0	≥ 144.00	≥ 144.13
Diastolic blood pressure (mmHg)	79.77	9.45	59.0 – 105.0	79.14	9.32	61.5 – 101.5	≥ 85.38	≥ 85.38
Waist-to-height ratio	0.54	0.04	0.47 – 0.64	.54	0.05	.44 – .64	≥ .56	≥ .57
Glycosylated haemoglobin (%)	5.03	0.47	4.3 – 7.1	4.99	0.41	4.3 – 6.7	≥ 5.20	≥ 5.13
Low-density lipoprotein (mmol/l)	2.53	0.83	0.88 – 4.59	2.51	0.83	0.45 – 4.36	≥ 3.05	≥ 3.15
Hair cortisol concentration (pg/mg)	150.50	261.27	26.24 – 1744.30	317.12	573.31	48.39 – 3765.11	≥ 143.62	≥ 305.51
High-density lipoprotein (mmol/l)	1.32	0.33	0.77 – 2.17	1.32	0.28	0.78 – 2.06	≤ 1.07	≤ 1.10
Heart rate variability by RMSSD (ms)	47.13	21.87	12.9 – 120.2	46.55	28.99	8.6 – 150.6	≤ 34.28	≤ 28.55

Table 19. ALI biomarker distribution and risk-quartile value at baseline and follow-up (n = 46). RMSSD, root mean square successive difference; SD, standard deviation

	Bivariate analysis		
Phase	Bivariate associations	*r*	P value
At Baseline	Waist-height ratio and High-density lipoprotein	-0.46	.001
	Waist-height ratio and Low-density lipoprotein	0.38	.009
At Follow up	Waist-height ratio and High-density lipoprotein	-0.58	<.001
	Waist-height ratio and Low-density lipoprotein	0.31	0.04

Table 20. Exploratory bivariate analyses of the ALI biomarkers in both phases

Regarding the main demographic variables, we did not observe any variable amongst those measured that impacted the AL measured in both phases (**Table 21**). However, we did notice an association that stood out, the relationship between biological sex and ALI in phase 2, where men reported significant AL compared to female firefighters. In addition, for the health and behavioural characteristics, firefighters who smoked tobacco, engaged in physical activities for less than 5 hours weekly, and slept for less than 6 hours daily reported higher AL (**Table 22**). Although the differences observed across the various health-related variables moved in the expected direction considering expectations with the AL model, none reached statistical significance.

Demographic characteristics	Allostatic load index Phase 1	 Phase 2
	Pearson's r coefficient ***(p value)***	
Age	0.26 *(0.086)*	0.21 *(0.17)*
Length of service (LOS)	0.15 *(0.31)*	0.11 *(0.43)*
	mean (SD)	**mean (SD)**
Sex		
Male	1.85 (1.42)	1.95 (1.6)
Female	1.67 (1.21)	.33 (.52)
P value *	*0.75*	*< .001*
Education		
High school diploma	2.50 (1.29)	2.50 (2.38)
College degree	1.87 (1.48)	1.87 (1.65)
University degree	1.44 (1.23)	1.11 (1.05)
Post-graduate degree	1.50 (.71)	1.00 (.00)
P value †	*.64*	*.41*
Rank		
Firefighters	1.78 (1.41)	1.72 (1.69)
Captain	2.20 (1.40)	2.20 (1.40)
Platoon chief	1.25 (1.26)	.75 (.96)
P value †	*.50*	*.31*
Relationship status		
Single	2.00 (.00)	2.00 (1.41)
Married/Common law	1.74 (1.35)	1.67 (1.60)
Divorced	5.00 (.00)	4.00 (.00)
P value †	*.06*	*.35*

Table 21. Demographic characteristics of sample and associations with the allostatic load index (ALI) score (n = 46). * P value determined by unpaired t-test, † P value determined by ANOVA test

	Allostatic load index	
	Phase 1	**Phase 2**
Health and behavioural characteristics		
Smoking		
Yes	2.25 (1.26)	2.25 (2.06)
No	1.79 (1.41)	1.69 (1.57)
*P value **	*.53*	*.51*
Marijuana use		
Yes	2.23 (1.54)	1.31 (1.6)
No	1.67 (1.32)	1.91 (1.59)
*P value **	*.26*	*.60*
Alcohol intake		
Never	1.00 (.00)	2.00 (1.41)
≤3 times a month	1.60 (.55)	1.80 (1.10)
Once a week	1.40 (1.27)	1.60 (1.84)
2-3 times a week	2.00 (2.00)	1.50 (1.41)
4-6 times a week	2.10 (1.38)	1.86 (1.77)
P value †	*.63*	*.98*
Physical activity		
< 2.5 h	1.67	1.56
2.5 – 5.0 h	2.05	1.81
> 5.0 h	1.63	1.75
P value †	*.62*	*.93*
Sleep pattern		
4-6 h	2.38 (1.19)	2.25 (2.23)
6-8 h	1.72 (1.51)	1.56 (1.5)
> 8 h	.82 (.33)	2.0 (1.10)
P value †	*.48*	*.52*

Table 22. Health and behavioural characteristics of sample and associations with the allostatic load index (ALI) score (*n* = 46). * P value determined by unpaired t-test, † P value determined by ANOVA test

8.4.5 Change in AL across time

After fitting the unconditional means model (UMM), we determined an intra-class coefficient (ICC) of 0.58, suggesting the existence of significant clustering, meaning that individual differences may explain 58% of the total variation in the AL within this sample of firefighters. Further, according to the unconditional growth model (UGM), 68% of the within-person variation in ALI is linked to linear increase over time (**Table 23**). In addition, the variance component associated with the random slopes was significant ($p < .01$), indicating significant individual differences in AL change across both phases. Finally, while determining the linear change (based on fixed effects) of AL within the UGM, there was a unit drop of 0.087 in ALI over both observation periods bringing the mean ALI to 1.74 at the follow-up phase; nevertheless, the reported change in ALI across phases did not meet the threshold for statistical significance ($t\,[45] = -0.43$, $p = 0.67$).

Variance components (parameter)		Model A (UMM)	Model B (UGM)
Level 1	Within-person variance (σ_{ε}^2)	0.935	0.297
Level 2	ID random effect (σ_0^2)	1.257	1.586
	In rate of change (σ_1^2)		1.268
Intraclass correlation coefficient $\rho = \sigma_0^2 / \sigma_0^2 + \sigma_{\varepsilon}^2$		1.257/1.257 + 0.935 = 0.58 ~ 58%	
Pseudo R^2 $R^2 = \sigma_{\varepsilon}^2(UMM) - \sigma_{\varepsilon}^2(UGM) / \sigma_{\varepsilon}^2(UMM)$		0.935 – 0.297 / 0.935 = 0.68 ~ 68%	

Table 23. The unconditional means model (UMM; Model A) and unconditional growth model (UGM; Model B) estimates and level of variance determination using the intraclass correlation coefficient and pseudo R^2 calculation (n = 46)

8.4.6 Psychosocial stress and Allostatic load

Following up on the findings from the unconditional models, there were significant variations in both initial status and the rate of change of the AL; hence, allowing us to go ahead with exploring the main effects of the substantive predictors (PSS-10 and SOOS-14) on AL. In model 1 (**Table 24**), we tested the study hypothesis that high perceived psychosocial stress would predict AL level and its slope over time. It was observed that work-related stress (SOOS-14) did not significantly affect the AL ($p = 0.65$); however, general life stress (PSS-10) was a significant predictor of AL at follow-up ($p = 0.03$). After accounting for perceived social support and age in model 2, general life stress remained a significant predictor of AL within the sample (**Table 24**). Adding the Covid-related-stress predictor (0 = No, 1 = Yes) in model 3 (**Table 24**), there was no significant change across the predictors except for the general life stress measure, which remained a significant predictor for AL; i.e., a unit increase in PSS-10 was associated with 0.10 increase in ALI by the follow-up (CI: .01, .19, $P = .039$).

	Conditional Growth Model		
Fixed effect parameters	Model 1 Coefficient (SE)	Model 2 Coefficient (SE)	Model 3 Coefficient (SE)
Intercept	0.38 (0.64)	-1.99 (2.03)	1.89 (2.04)
TIME	-0.10 (0.21)	-0.10 (0.20)	-0.10 (0.20)
PSS-10	**0.10 (0.04) ***	**0.10 (0.05) ***	**0.10 (0.04) ***
SOOS-14	-0.02 (0.05)	-0.04 (0.05)	-0.05 (0.06)
Age		0.04 (0.02)	0.04 (0.02)
SSS-FF		0.02 (0.04)	0.02 (0.04)
C19			0.30 (0.38)
Random effect parameters (variance components)			
Within-person σ_2	0.28	0.27	0.52
Intercept	1.44	1.32	1.14
Model fit			
LL	-153.88	-152.39	-152.06
BIC	343.94	349.99	353.86

Table 24. The conditional growth model depicting the fixed effects (top), random effects, and model fit (bottom) for models of the predictors of AL **(***n* = 46**)**. * p value < 0.05. SE, standard error; LL, log-likelihood; BIC, Bayesian Information Criterion

8.5 Discussion

This study investigated the longitudinal patterns of AL and its correlation to psychosocial stress by collecting a range of demographic, behavioural, and physiological measures from a sample of 46 active firefighters from a mid-sized urban region in Southern Ontario. In doing so, we sought to make the first application (to the best of our knowledge) of the allostatic load concept within this professional group of first responders to objectively appraise whether psychosocial stress might predict physiological imprint over time.

Firstly, we examined the prevalence of perceived general-life stress and work-related stress, two frequent presentations of psychosocial stress within our sample of firefighters. In terms of perceived general life stress measured using the PSS-10, we observed a relatively high perceived stress level in our sample compared to other groups of firefighters that have reported this type of stress. For example, the reported PSS-10 score was 22% and 4% higher than that observed in Lee et al. (2014) and Makara-Studzińska et al. (2019). In addition, among our sample, three-quarters of the participants reported feeling nervous or stressed at least some of the time. Such a finding is particularly alarming when considered within the context of the nature and demands of firefighting since a core tenet of the job includes composure and mental repose.

In contrast, participants did not report high levels of work-related stress, especially in comparison with the previously examined group of firefighters in two studies, Kimbrel et al. (2015) and Stanley et al. (2018), that used the SOOS-14. Nevertheless, two areas of concern stood out: poor diet and perceived sleep disruption. In our sample, the effect of poor diet was visible as the average waist-to-height ratio was slightly higher (M = 0.54) than the accepted sub-clinical threshold (0.5; Ashwell et al., 2012). Moreover, in both study phases, a higher waist-to-height ratio was significantly linked to elevated LDL and low HDL, indicating a growing risk for adverse health complications such as obesity and cardiometabolic disorders (Sotos-Prieto et al., 2017; Wang et al., 2016). Therefore, a likely explanation for the poor diet could be the eating culture in fire stations. Seemingly, firefighters contend with unreliable meal planning and poor dietary habits (intake of high-calorie and large meals) due to 24- to 48-hr shifts, frequent calls, and inactive periods between calls (Bongkyoo Choi, Dobson, et al., 2016; Dobson et al., 2013; Sotos-Prieto et al., 2017).

Sleep disruption and working with a demanding co-employee were also reported in a Canadian study investigating occupational stressors in a large group of firefighters using the SOOS-14. (Isaac & Buchanan, 2021). Sleep disruption leading to excessive daytime sleepiness and worsening sleep quality may be a consequence of long shifts (>48-hour shifts) and frequent emergency calls (Haddock et al., 2013; Yook, 2019).

The impact of Covid-19 within our sample was substantial as almost half of the sample reported stress attributed to the pandemic. This finding was not surprising, given that firefighters were among a specially designated group of frontline workers expected to perform their duties despite rising infection rates, especially during the pandemic's peak (Lima et al., 2020). Indeed, their status as first responders and frontline workers may have contributed to higher physical and mental stress from perceived higher virus exposure from public and workplace interactions and the need to adhere to protective measures, including social distancing and self-isolation from colleagues and family (Vujanovic et al., 2021).

Regarding social support, participants reported high levels of support from colleagues and family members. Despite the reported level of social support, we observed a trend suggesting that perceptions of social support also declined with age and length of service; nevertheless, the strength of the relationships was too weak for us to draw any firm conclusions. Remarkably, female firefighters reported feeling more significant social support than their male counterparts. Since female participants reported lower overall stress levels and AL scores, a high perceived social support likely contributed to this finding based on the "buffering hypothesis", which posits that psychosocial resources like social support may buffer job-related stress (Bakker & Demerouti, 2007).

Further, based on our longitudinal model, we conclude that firefighters who had a greater ALI at baseline had a negligible increase in AL over time. Although the within-firefighter change in AL over time was insignificant, we expected otherwise based on the AL model, which assumes an incremental physiological "wear and tear" with time (Crimmins et al., 2003). A likely reason for this finding might be that a year difference between both phases was not enough time to observe an appreciable degree of change in the AL. On the other hand, in support of our hypothesis, we observed a positive association between psychosocial stress and AL over time. In detail, our analysis revealed that general life stress measured at baseline was a significant predictor of higher AL at phase 2 within our sample of firefighters. Moreover, this relationship remained strong even after accounting for firefighter age, the effect of social support, and Covid-19-related stress.

These findings are consistent with suggestions that general-life psychosocial stress may be a strong predictor of AL by exerting a deleterious effect on the physiological systems over time, ultimately leading to adverse health outcomes (Christensen et al., 2019; Clark et al., 2007). In addition, our findings regarding general life stress and AL agree with a recent cross-sectional study by Mauss & Jarczok (2021). They reported a significant association between AL and perceived general life stress in a sample of 1421 participants. Similarly, Clark et al. 2007 found a significant association between general life stress (psychological stress within the study context) and components of AL (i.e., primary mediators). The positive association between general life stress and AL have also been confirmed in two other studies (Glei et al., 2007; Hawkley et al., 2011).

Conversely, the relationship between work-related psychosocial stress failed to meet the statistical significance threshold. This finding was unexpected, given that previous studies employing allostatic load assessments to capture the physiological imprint of work-related stress have consistently identified significant associations between work-related stress and AL within their samples (Bellingrath et al., 2009; Mauss, Jarczok, et al., 2015; Schnorpfeil et al., 2003). Similarly, Covid-19-related stress had no noticeable effect on psychosocial stress, and the AL recorded within our sample; however, it displayed a stronger link to baseline work-related stress. The lack of association between psychosocial stress and COVID-19-related stress might have ensued from differences in time of measurement; psychosocial stress was assessed in phase 1, while COVID-19-related stress was measured in phase 2. Based on previous evidence suggesting a link between psychosocial and COVID-19-related stress (Pedrozo-Pupo et al., 2020; Yan et al., 2021), if both variables were assessed concurrently, we might have arrived at a significant association between both variables. Perhaps, this finding may also help elucidate the inability of work-related stress to predict AL at follow-up, since a potential spillover effect from Covid-19-related stress may have lessened its impact; however, in contrast, general-life stress remained unaffected.

Our findings show that age and social support measured at baseline did not significantly impact the association between psychosocial stress and AL at follow-up. In particular, the finding regarding age fell short of expectations, given that the AL model posits an increase in ALI with age, a consistent finding observed within data from other occupational groups (Schnorpfeil et al., 2003; J. Sun et al., 2007) and the general population (Crimmins et al., 2003; Seeman et al., 2001). Despite failing to predict AL within our sample, age was significantly linked to work-related psychosocial stress. We could argue that older and long-serving firefighters are more likely to be experienced and higher in the hierarchy, thus accorded more responsibility that may predispose them to more significant work-related stress. Although we found no effect of social support on AL, this finding could be linked to the presumption that younger adults tend to hold social relationships/support in lesser regard than their older colleagues. Indeed, older adults value social relationships/support more (Brooks et al., 2014;

Carstensen et al., 1999). This notion may explain how firefighters, especially our sample of young and healthy participants, perceive social support and how this resource buffers the effect of perceived stress levels and AL.

8.5.1 Strengths and limitations

There are several strengths of this study. First, in addition to the novel application of the AL model in firefighter research to investigate psychosocial stress impact, our study is the first to explore this impact among firefighters longitudinally. To the best of our knowledge, the relationship between Covid-19-related stress and ALI has yet to be investigated. Albeit not the primary focus of our study, given the significant impact of the Covid-19 pandemic on the general population and first responders, in particular, its consideration and assessment were vital to the significance of our findings. Secondly, in compiling the AL index, we incorporated primary mediators in cortisol and HRV. Despite a sound recommendation to include primary mediators in any compilation of the AL index to accurately reflect physiological stress responses and the cumulative systemic wear and tear, these assessments are not commonly part of routine datasets (Doan, 2021; Mauss, Li, et al., 2015). Understandably, cortisol assessments and equipment required for HRV assessments require technical know-how and significant financial commitment. Hence, our assessment of both neuroendocrine and cardiometabolic biomarkers accords further credence to our findings.

Finally, our study is among the few studies (Christensen et al., 2019; Clark et al., 2007) that have distinguished the different presentations of psychosocial stress when investigating associations with AL. Our investigation of work-related and general life stress allows us to distinguish the presentation of psychosocial stress within firefighters more clearly and explicitly examine AL and its links to adverse health outcomes.

Despite the contributions we feel have been made by our work, the limitations of this study must be acknowledged. The first limitation of our study was the sample size used to perform our analysis. Unfortunately, despite significant recruitment efforts and firefighter engagement between phases, participation was low, and we lost a sizeable number of firefighters to attrition, which may occur with longitudinal studies. The size limitation may have constrained our capacity to reach the statistical power necessary to observe patterns between our variables of interest precisely. Secondly, our sample comprised mainly healthy (low-risk health behaviours), middle-aged, educated, male firefighters of European descent. The sample's homogeny could limit the generalisability of our results; however, given the lack of national-level data regarding the demographic characteristics of Canadian firefighters, our report's external validity remains unclear.

Furthermore, we were also limited to a few participating female firefighters; hence we could not pursue a sex-stratified analysis despite previous studies suggesting a potential effect of biological sex on the PS-AL relationship (Juster et al., 2013; Mair et al., 2011). Addressing this limitation will require a diverse sample to capture changing demographics within firefighting, especially considering urban centres with more heterogeneous workforces than that captured in the current report. Finally, we relied on self-reported measures to assess psychosocial stress, covid-19-related stress, and social support; our results may be subject to recall bias or response bias (that is, either under, or over-reporting)

8.6 Conclusion

The findings from this study highlight two types of psychosocial stress presentation and elucidate their associations with AL in firefighters. First, our findings show for the first time that psychosocial stress presented as general-life stress was a significant predictor of AL over time in a sample of firefighters, independent of age, social support, and Covid-19-related stress. Unexpectedly, work-related psychosocial stress failed to predict ALI within our sample of firefighters. Further, Covid-19-related stress was prevalent among our firefighters. Given that firefighters had to perform their duties despite the series of lockdowns, the negligible effect on AL was intriguing and should warrant further investigation.

Emerging findings suggest that addressing life and work-related psychosocial stress may be a potent target area to support the health and wellbeing of firefighters. Specifically, the observed influence of general-life stress suggests that health promotion activities should translate beyond the immediate work environment and include a more holistic approach to alleviating the cumulative effect of such stressors. Additionally, addressing the lack of control within this occupational group requires a commitment to providing them with the right tools, support, and training to overcome the stress brought about by worry and uncertainty about the job. Also, favourable work-life and work-family balance will contribute to firefighters' wellbeing.

Interventions to address work-related stress should be considered as well. Such interventions include allocating time for physical activity, effective sleep hygiene, nutrition education programmes, and team cohesion activities. Similarly, information campaigns and interventions (e.g., frequent testing and encouraging vaccine uptake) will help ease the burden of Covid-19-related stress.

In sum, we firmly believe that the allostatic load framework remains valuable for investigating psychosocial factors that may influence firefighters' health over time. Its application provides us with a "window of opportunity" to identify high-risk firefighters, implement stress-relieving activities, and allocate resources to prevent the development of chronic disease.

Chapter 9
GENERAL DISCUSSION

The primary objective of this dissertation was to explore the psychosocial stress experience of firefighters and how these stressors become biologically embedded to cause adverse health outcomes by investigating the psychosocial stress-allostatic load relationship. This general discussion aims to summarise the results across the studies in this thesis, highlight the key contributions of these findings to the extant literature, and suggest future directions for research in this field.

9.1 General findings

The primary objective of chapter 3 was to introduce the AL model as a framework to investigate the multi-systemic impact of psychosocial stress exposure on the health and wellbeing of firefighters. Psychosocial stressors within this professional group can be profound and enduring, and, as described in the study, the most noticeable impact may be the consequences on firefighter health and mental wellness. Indeed, with the increasing prevalence of chronic adverse health outcomes in this group and the accompanying cost to individual health, public health, and safety, a compelling case can be made to support the application of the AL model as a framework to elucidate the psychosocial stress phenomena in firefighters comprehensively. In addition, previous applications of the AL model within other occupational groups, including their findings, support the framework's incorporation into firefighter stress research.

Furthermore, the study offered a non-exhaustive list of primary and secondary variables that merit consideration when applying the AL model to investigate stress impact on firefighters. The primary variables include the key ones most likely to be investigated: the stress exposure, the AL measure/index, and the adverse health outcome (somatic, or mental). The secondary variables identified were compiled from the current stress literature focused on first responders, especially firefighters. Variables listed include non-modifiable factors such as sex, age, and ethnicity and modifiable factors such as psychosocial resources (e.g., social support) and behavioural habits like alcohol intake.

Foremost among the listed advantages of applying the AL model within this group is the framework's ability to address, or account for confounding, or moderating factors. An example offered was the healthy worker effect, which may mask some of the impact of stress within this occupational group. In addition, the capacity of the AL model to serve as a biological warning system for firefighters at risk of disease was highlighted.

Similarly, the study discussed potential challenges that may be encountered in applying the AL model within research focused on the stress experiences of firefighters. In particular, the following challenges were discussed: the significant cost, effort, and technical know-how required for specific biomarker collection, logistical bottlenecks, and a lack of concordance between perceived stress assessment (subjective measure) and the allostatic load index owing to the unique job-related traits exhibited by firefighters. Nevertheless, given the importance of the AL model and its growing interest, the study concludes with a recommendation supporting the operationalization of the framework within research aimed at firefighter stress experience.

Chapter 5 presented an empirically supported standard reference value for HCC in healthy (non-clinical) adults. Cortisol is a frequently measured biomarker in different ALI construction, and recent application/utilization of HCC has contributed to methodological advancement and accuracy in systemic cortisol assessment. However, given the study's objectives, which included measuring primary mediators (e.g., cortisol) to ascertain the effect of psychosocial stress on the sample of firefighters, the lack of a reference value for HCC in healthy adults was immediately apparent. The importance of such a value within the context of this study lies in its application for computing the ALI based on the clinical (norm) threshold count-based method (Juster et al., 2010). Hence, a unique opportunity was provided to address the methodological question of what value could be used as a reference threshold for HCC in healthy adults.

After aggregating data from the 17 eligible studies that used immunoassays, a widely used method for HCC analysis, an upper limit (i.e., the mean plus two SDs) of 240 pg/mg may be a reasonable border for extreme observations within a healthy adult population measured via immunoassay. Further, beyond determining an HCC normal adult reference value, frequently deliberated factors that may influence the HCC value obtained using immunoassay were highlighted. For example, hair care and treatment, contraceptive use, behavioural habits like tobacco and alcohol consumption, and body composition variables. Although these factors were highlighted in different contexts and intensities, none have been acknowledged to impact the HCC value consistently; however, growing consensus suggests consideration while interpreting results. Another interesting finding, albeit not the desirable type, was the frequent absence of stratification of HCC based on key demographic variables like sex and ethnicity. However, since there is no agreed-upon HCC reference value based on sex, race, and even age, research should be prioritised to determine such values.

While the determined reference value for HCC in healthy adults was not ultimately used as part of the computation for ALI in both empirical studies investigating the PS-AL relationship, the effort was worthwhile when considering the importance of such a value. With time and opportunity, an investigation of the PS-AL relationship based on ALI scores derived from clinical (norm) cut-offs, including HCC, would be of interest to observe how both count-based methods (i.e., risk quartile and clinical cut-offs) differ, or agree in their assessment of AL within firefighters.

Chapter 6 aimed to identify and synthesize the evidence on work-related psychosocial stressors and their known outcomes in firefighters. Before this study, no attempt had been made to consolidate evidence on the prevalence and severity of work-related psychosocial stressors in firefighters. In addition, exposing prevailing stressors and their outcomes was productive in offering justification and validation for applying the AL framework, which will help explain the stress-disease outcomes within this occupational group.

After a rigorous literature review using robust inclusion criteria, 29 studies met the eligibility criteria and were included for data extraction. A noteworthy finding from the systematic review was the extent of methodological heterogeneity observed across the eligible articles. For example, studies employed different research designs (mostly cross-sectional) and used different subjective stress assessment measures, including the PSS, SOOS, and even non-validated questionnaires.

Work-related psychosocial stress influenced the health and wellbeing of firefighters in significant ways; however, the breadth to which its effect reached was quite alarming. The effects ranged from neurobehavioral to specific somatic complaints, which were grouped into six themes: depression-suicidality, non-depressive mental health problems, burnout, alcohol use disorders, sleep quality, and somatic disorders. Among some of the acknowledged stressors impeding the health and function of firefighters, the following stressors were consistent across all themes: high job demands, interpersonal conflict, poor perception of workplace fairness and the work environment/climate. The recurring issue of poor perception of one's workplace, including perceptions of discrimination and harassment, was worthy of note, primarily because of the assumed nature of relationships and culture common among firefighters (e.g., camaraderie and shared activities).

Interestingly, amidst the reported stressors, specific factors contributed to building the resiliency of firefighters: self-efficacy, availability of social support, and distress tolerance. The contextual importance of social support in these findings cannot be overstated since there is established evidence linking psychosocial resources with physiological regulatory processes (Taylor & Seeman, 1999).

Thus, identifying various psychosocial stressors encountered by firefighters and associated health outcomes and spotlighting supportive resources that may absorb the stress impact addresses an essential aspect of the main study's objectives. In addition, the findings provide sufficient grounds to investigate the underlying link between psychosocial stress and health and behavioural outcomes.

Chapter 7 provided a cross-sectional investigation into the relationship between psychosocial stress and allostatic load in a sample of Canadian firefighters. The study examined a vital stage (i.e., the underlying mechanism explained by AL) in the cascade of events leading from psychosocial stress exposure to adverse health outcomes. Notably, two prevalent presentations of psychosocial stressors were investigated: work-related and general life stress. However, work-related stress was the primary focus of the investigation.

There was a moderate level of perceived psychosocial stress among the firefighters; however, general life stress was more pronounced. Some areas of concern contributing to the perceived psychosocial stress were: lack of control, general nervousness, poor diet, sleep disruption, and exposure to demanding colleagues. As expected, work-related and general life stress was significantly correlated, and longer-serving firefighters reported higher work-related stress than their younger colleagues. Among the behavioural habits investigated, physical activity had a dampening effect on psychosocial stress. Furthermore, high perceived social support from family members and work colleagues appeared to offset the effects of psychosocial stress in the participants. Specifically, female firefighters reported significantly more social support than their male counterparts.

Although the directional relationship between psychosocial stress and AL matched the hypothesized direction, a positive one, the strength of association was non-significant. When AL was regressed on psychosocial stress in a model including age, length of service, and the direct and moderating effect of social support on both stress presentations, the predictive effect of both psychosocial stress measures was negligible. Moreover, social support played no direct, or moderating role in the PS-AL relationship. Nevertheless, age appeared to be a significant predictor of AL within the sample of firefighters.

Whereas the strength of the association between psychosocial stress and AL was not congruent with expectations, the positive direction of the association was in line with the steady, but progressive "wear and tear" from stress embedding underpinning the AL theory. Furthermore, the additional finding between age and AL was notable since compelling evidence suggests AL rises with age, reflecting cumulative "wear and tear" (Karlamangla et al., 2002; Seeman et al., 1997). Albeit not precisely the findings hoped for, it provided a foundational framework to build on and motivation to complete a longitudinal analysis to look into the PS-AL relationship over time, thereby overcoming limitations typically observed with cross-sectional analysis.

Chapter 8 presented the longitudinal analysis of the relationship between psychosocial stress and allostatic load within the sample of firefighters in a one-year observation period. The longitudinal analysis was a vital part of the research considering the AL assumption of cumulative wear down from repeated insults over time. Although limited to 2 phases, the analysis provides a more in-depth analysis of AL progression in firefighters; specifically, it allowed us to examine factors that might influence any change in AL observed across the 2 time points.

Between both phases of data collection, cases of COVID-19 rose, and a worldwide pandemic ensued. The rapid transmission rate of the COVID-19 virus and the substantial burden on individual health and public health resources caused considerable stress across the board. Moreover, given the nature of work in the fire service, especially in the role of first responders, they were not spared from the COVID-19-related pandemic stress. Hence, to completely capture the stress experience during such a time, it was necessary to acknowledge the stress from the COVID-19 pandemic as a potential confounding variable within the PS-AL relationship.

Due to the longitudinal nature of the study, there was some attrition. Hence, a full case analysis (i.e., only participants providing complete data in both phases) was completed using the linear mixed effect model. Baseline assessments of psychosocial stress and social support were used while data on COVID-19-related pandemic stress was retrieved from the sample during phase 2. Age, rather than length of service, was used for analysis since it predicted AL in the cross-sectional analysis and was a better fit to avoid collinearity between both variables.

The reported prevalence of perceived general-life and COVID-19-related pandemic stress was concerning; however, stress related to the pandemic was expected considering the unknown nature of the COVID-19 virus at that time and the significant general and workplace changes that followed. In addition, there was significant variation from individual differences linked to AL changes across both phases. Further, no substantial change in AL was found between phases 1 and 2; however, firefighters with elevated ALI at baseline were most likely to continue on that trajectory at follow-up.

The study revealed that general-life psychosocial stress measured in phase 1 was significantly linked to elevated AL by the follow-up phase after accounting for firefighters' age, perceived social support, and COVID-19-related pandemic stress. In contrast, work-related psychosocial stress measured at baseline was not associated with AL in this sample of firefighters. Similarly, age failed to significantly predict AL by the follow-up phase within this sample despite earlier findings on its positive association with AL.

In sum, the positive association between psychosocial stress and AL within the sample of firefighters was significant, mainly because it was in accordance with our hypothesis based on the AL model and what has been observed in other occupations. However, it calls attention to the importance of approaching the psychosocial stress-AL relationship beyond investigations focused solely on workplace factors while considering other possible presentations of this stressor, especially within firefighting.

9.2 Highlights of the thesis and its contribution to research

The arrival at a potential threshold value for HCC has substantial research and clinical implications. First, the choice to provide a standard reference value in healthy adults using immunoassay analytical methods is useful considering widespread immunoassay access, usability, and dependability based on minimal variability between the different immunoassay methods (Russell et al., 2015). Secondly, for stress-related research, the clinical reference value offers researchers opportunities to move past traditional invasive methods (e.g., venipuncture) for systemic cortisol assessment and an empirically supported threshold to determine the ALI based on the clinical threshold count-based method.

Further, researchers, including clinical personnel, now have a reasonable range to distinguish normal versus pathological states from hair cortisol concentration for bio-physiological research. For example, the upper limit of HCC (aggregate mean plus 2 SDs), that is, 241 pg/mg, could serve as a cut-off value to signal risk for hypercortisolemia, or Cushing's disease. The upper limit value agrees, or falls within previous determined values/cut-offs for Cushing's disease, for example, 221 pg/mg (Thomson et al., 2010) and 267 pg/mg (Hodes et al., 2017).

The finding on prevailing psychosocial stressors and related outcomes was vital in providing a rationale to apply the AL model to investigate psychosocial stress in firefighters.

Although the findings have been well discussed, two discoveries stood out. First, witnessing how far-reaching psychosocial stress consequences affected firefighters' health and wellbeing was concerning. Significant strides have been made to improve equipment, procedural standards, and protective gear to reduce job hazards inherent to firefighting. Similar effort and commitment should be directed toward addressing psychosocial stress. Secondly, given the potency of social support, self-esteem, and distress tolerance at cushioning stress impact, reasonable interventions centered around promoting these resources, especially with policies, training, and resource allocation, will help significantly.

For both empirical studies, it is reasonable to conclude that psychosocial stress was a major actor when considering the health trajectories of firefighters. One notable finding beyond the association between psychosocial stress and AL was the relationship between psychosocial stress and the individual components of the ALI. Interestingly, perceived general-life psychosocial stress affected the cardiometabolic biomarkers with greater strength and frequency. In more detail, higher perceived life stress significantly elevated systolic and diastolic blood pressure and lowered HDL (i.e., the good cholesterol). Further, there was a significant elevation of HCC (~110% increase) between phases 1 and 2, and although there was no bivariate correlation between cortisol and both stress measures and COVID-19-related stress, it signals the presence of a potent stressor, or event causing this drastic shift. The HCC mean derived in phase 2 (M = 317.12 pg/mg) was well above the upper-limit reference value (240 pg/mg) we determined for HCC in healthy adults. Such a finding begs the question, what other factors/stressor/event was responsible for this? Could it be a total stress effect (psychosocial stress combined with COVID-19-related stress)? An in-depth investigation into this phenomenon would be the best step forward.

Another finding worth highlighting was the change in the age-AL association between findings from both empirical studies. During the cross-sectional investigation into the PS-AL relationship, age was a significant predictor of AL, which was very much in line with the AL theory. However, during the longitudinal analysis, the firefighter age was not associated with AL by the follow-up phase. Despite the unexpected finding, a possible explanation might be that the lack of predictive ability may be related to the one year between phases being an insufficient amount of time to clearly observe changes in the AL linked to age. Also, another explanation might be linked to the age of firefighters that dropped out; they were relatively older than the sample participants (sample mean = 41 years, mean age of those who did not continue = 47 years). Since participants that dropped out were older and may not have been at the same state of health or maintained similar degree of physical activity as their younger counterparts that remained in the final sample, it may also have contributed to the healthy worker effect commonly observed among firefighters, (Rosenstock et al., 2007) and may be an important consideration for researchers using longitudinal designs

The inability to find an association between <u>work</u>-related stress and AL with both study designs was likely fortuitous given what is known about this association from previous research. Several reasons may have contributed to this finding; however, one immediately comes to mind. The severity, or impact of work-related stress may vary across fire stations, or geography; beyond individual factors that provide resiliency towards stress, the work environment, leadership, and administrative support specific to the culture of a fire station play significant stress mitigating roles (Beaton et al., 2001; Beaton & Murphy, 1993; Nieuwenhuijsen et al., 2010). That is, fire stations will perform better where these factors are enshrined in their culture. Since participants reported low-stress levels related to their jobs, an argument can be made that the culture within the fire department contributed to the reported stress levels observed. Further, even though the social support assessment may not have explicitly distinguished the general perceived support from the administrative type, participants enjoyed broad support, which may have lessened the perception of work-related stress.

Regarding geography, the difference between larger and smaller urban jurisdictions may influence the degree of work-related stress experienced by firefighters. Larger fire departments, especially those in big cities, or towns, will likely have a more heterogenous workforce with diverse experiences. In such instances, differences in perceptions of stress or the availability of psychosocial resources may be more pronounced, unlike that observed with homogenous samples like the one used for both of the presented studies. Indeed, the findings would likely differ when considering fire departments from a larger metropolitan area like the City of Toronto, with an even more diverse workforce and complex job demands. Given that this study was the first attempt at examining work-related stress within a smaller urban area in Waterloo, the findings are vital to helping us acknowledge the likely effect of the location to understand the true nature of the AL trajectory within this occupational group.

Further, jurisdictions that employ full-time firefighters are more likely to provide adequate pay and benefits, thus alleviating a critical source of work-related stress: effort-reward imbalance (Siegrist, 2016). Members of the Waterloo Fire Rescue receive adequate pay and benefits based on the collective agreement with the municipality; to what extent this may have contributed to the low work-related stress is yet to be determined since remuneration was not accounted for during the analyses.

Finally, the revelation of the association between general-life stress and AL was timely and vital. Among the observations, the link between general-life stress and the cardiometabolic component of the ALI necessitates immediate action due to the growing risk for cardiovascular disease and because it remains a leading cause of morbidity and mortality among firefighters (Mathias et al., 2020; Pedersen et al., 2018; Soteriades et al., 2011).

9.3 Future research considerations

Several research recommendations have been provided within each chapter; nevertheless, some require urgent consideration. First, despite the novel and important application of the AL model on a sample of Canadian firefighters, more domestic research effort is urgently needed. That is, quite often, assertions and impressions on firefighter health and wellbeing have been made using data from the USA. Despite the presence of similarities, given geographic proximity and shared values, significant differences relating to race, funding sources, and cultures may make the Canadian experience distinct. Creating a complete picture of the AL of firefighters and first-responders alike will require contextual demographic and geographical factors that represent their stress experience in its entirety. Also, more representative nationwide data will allow for the development of stress assessment measures tailored to capture psychosocial stress experienced within the Canadian context.

Secondly, more experiments with a diverse group of individuals should be the next step forward. Regardless of the study design, researchers should aim to recruit heterogeneous samples with diverse experiences to make it easier to generalise findings to the broader population of firefighters and first responders. Furthermore, beyond firefighters, another positive step will be the inclusion of other first responders (e.g., police) within such recruitment efforts since they share a similar hierarchical structure and perform high-demand jobs. Such action would prove useful in providing rich information on their different stress experiences and AL trajectory differences.

The AL model has proven to be a reliable and feasible framework for population-level inquiry and determining stress-disease mechanisms. Despite this, several aspects of the AL model require standardization, given the wide variability in its methodology. For example, there is a lack of consensus on which ALI computation method provides the most precise reflection of AL. In particular, the motivation to use any of the popular methods of ALI computation mostly depends on the researcher's aspirations, or objectives. However, for the framework to enjoy widespread acceptance by clinicians, researchers, public health analysts and policymakers, a guiding standard operating procedure that harmonizes best practices for data collection, data (or sample) storage, ALI computation, and interpretation will contribute an enormous deal. Hence, reports, systematic reviews, and/or more empirical studies designed to synthesize data within this field should be conducted.

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Licensed ContentAuthor	Somkene Igboanugo, Philip L. Bigelow, John G. Mielke
Licensed ContentDate	Mar 29, 2021
Licensed ContentVolume	63
Licensed ContentIssue	1
Licensed ContentPages	22
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Portion	Full article
Will you be translating?	No
Title	Biological Embedding of Work-Related Psychosocial Stress in Firefighters
Institution name	University of Waterloo
Expected presentation date	Jul 2022
Requestor Location	Somkene Igboanugo1-417 KeatsWay Waterloo, ON N2L 5S7Canada Attn: University of Waterloo
Publisher Tax ID	EU826007151
Total	0.00 CAD

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Appendices

Appendix A – Information letter and consent form

You are invited to participate in a study that will try to understand whether the occupational factors experienced by firefighters can impact their health and well-being.

What You Will Be Asked to Do

You will be asked to complete 6 questionnaires that ask about your background (e.g., gender, ethnicity), various health-related conditions and behaviours (e.g., smoking, physical activity), your perceptions of general life stress during the last month, your social support network, and your views about psychological health and safety in your workplace. Some of the questions in the surveys are sensitive in nature; for example:

- In the last month, how often have you felt unable to control important things in your life?

- In the last month, how often have you felt unable to cope with everything you had to do?

Completing the questionnaires will require about 20 minutes.

Please note that you always have the option of choosing not to respond to any question, or to speak with a researcher if you have concerns about a question.

You will also be asked to allow the measurement of the following biological characteristics:

1) blood pressure and heart rate variability (to measure heart rate variability, a small amount of chest hair may need to be shaved to permit attachment of 2 electrodes)
2) height and weight (to allow your body-mass index to be determined)
3) waist circumference (to allow your waist-to-height ratio to be determined)

Lastly, you will be asked to allow two biological samples to be collected:

1) a small sample of hair from either the top of your scalp, or the nape of your neck
    a. the researcher will use a pair of scissors to remove about 75-100 strands of hair (about 10 mg) from as close to your scalp as possible
    b. the sample will be used to allow for the measurement of stress hormones
2) a small amount of blood from one of your fingers
    a. you will collect a few drops of blood from one of your fingers using a fingertip prick device similar to ones used by individuals with diabetes for routine blood glucose testing
    b. the blood sample will be placed onto a test strip that will be fed into a portable testing device to measure the level of sugar and fats present in your blood

NOTE: detailed instructions about how to collect the blood sample will be provided by the researcher, who will be present and able to provide guidance.

Please note that you have the option of not providing any one of the biological measures, and may speak with the researcher about any concerns you may have, or stop the data collection procedure, at any point. Finally, please bear in mind that your identity in relation to your answers and biological measurements will remain confidential, and will only be used for the purposes of this research study.

Participation

Our study should require about 30 minutes to complete. Your participation is voluntary, and whether you choose to participate will not affect your professional standing, or your relationship with your employer.

You may choose to withdraw from the study at any time if you wish with no penalty, and can remove your information at any time up to the point of publication of the research by contacting the faculty investigator.

Lastly, please note that our study is not meant to provide a clinical diagnosis of any sort, so participants will not be informed of the results from the hair and blood analyses.

Benefits of the Study

Although there are no direct personal benefits to your participation in our study, our research will help to improve our understanding of the psychological health and well-being of public safety personnel (in particular, firefighters), and to determine whether their occupational experiences may "get under the skin" in such a way as to increase their likelihood of developing a range of chronic diseases.

Risks to Participation in the Study

Some of our questions may be viewed as sensitive in nature. For example, we ask participants to reflect upon their current level of stress, their physical and psychological health concerns (e.g., diabetes and blood pressure), and their adoption of health-risk behaviours (e.g., cigarette and alcohol use). Some participants may experience discomfort when reflecting upon these kinds of questions. Please keep in mind that you may speak with the researcher about any question before you provide a response, you may choose not to respond to any question for whatever reason, you may withdraw your participation at any time without penalty, and you may speak with the faculty investigator if you have questions/concerns related to the study.

During the collection of the blood sample, some participants may feel lightheaded, while others may experience a slight amount of bruising at the spot where the skin was punctured with the lancet. As well, there is a very slight risk of infection at the site where the skin was punctured. To reduce the risks associated with the blood collection, the area of the finger to be used will be cleaned with an antiseptic prior to the skin being punctured, and, afterwards, participants will be asked to sit quietly for up to 10 minutes and apply pressure to the finger that was used.

Confidentiality

Your identity will be kept confidential. Paper-based data will be stored in a locked file cabinet in a locked office in the research laboratory of Dr. John G. Mielke. Electronic data will be stored in an encrypted format on a password protected computer. Data from this study will be stored for at least 7 years, and will only be accessed by researchers involved in this study.

Results of the study will be presented (e.g., conference presentations, papers) at the group level only. It will not be possible to determine any individual participant's data from the results, nor will the results of any individual be shared.

Questions and Research Ethics Clearance

If, after receiving this letter, you have any questions, or would like additional information to assist you in reaching a decision about your participation, please feel free to contact the faculty member listed below.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE #31228). Participants with questions about their involvement in the study may contact the Office of Research Ethics at 1-519-888-4567, extension 46005, or ore-ceo@uwaterloo.ca.

Faculty Investigator:

John G. Mielke, PhD, CBiol

Student Investigator:

Somkene Igboanugo, MD

Thank you for your interest in our research and for your assistance with this project.

CONSENT OF PARTICIPANT

By signing this consent form, you are not waiving your legal rights, or releasing the investigator(s), or involved institution(s) from their legal and professional responsibilities.

I have read the information presented in the information letter about a study being conducted by Dr. John G. Mielke and Dr. Somkene Igboanugo of the School of Public Health Sciences at the University of Waterloo.

I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study without penalty at any time by advising the researchers of this decision.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE #31228). If you have questions for the Committee, please contact the Chief Ethics Officer, Office of Research Ethics.

For all other questions, please contact either Dr. Mielke, or Dr. Igboanugo:

Faculty Investigator:

John G. Mielke, PhD, CBiol

Student Investigator:

Somkene Igboanugo, MD

____
Print Name

____
Signature of Participant

____
Dated at Waterloo, Ontario

____
Witnessed

____
ID Number

Appendix B – WFS Participant Preparation letter

In the coming weeks, you will meet with researchers from the University of Waterloo who are trying to understand whether the occupational factors (particularly stress) experienced by firefighters can impact their health and well-being.

To aid in the data collection, please try to:

a) Avoid consuming coffee, or exercising on the day of your appointment (since these may interfere with the recording of your heart rate and blood pressure).

b) If possible, postpone having your hair cut until after the appointment (to ensure that at least 1 cm of hair may be collected for stress hormone analysis).

c) If possible, trim your chest hair to permit the attachment of electrodes that will be used to measure heart rate variability; please see the diagram below for guidance on where the electrodes will be placed:

If you are unable to shave your chest hair in the areas where the electrodes will be placed, then we will do so on the day of your appointment.

Thank you for your interest in our research and for your assistance with this project.

If you have any questions, or would like additional information, please feel free to contact the faculty member listed below.

John G. Mielke, PhD, CBiol

Appendix C – Demographic Questionnaire

INSTRUCTIONS: Please provide the following information about your background. Although your identity will remain confidential, if you do not feel comfortable answering a question, please leave the answer blank.

1. **Age**: ____________

2. **Gender**: Female ☐ Male ☐ Prefer to self-identify ☐ Prefer not to answer ☐

3. **Length of service** (years and months): ____

4. **Rank**: ____

5. **Relationship Status**: Married/Common Law/Long-term relationship (1+ years) ☐ Divorced/Widowed ☐ Single ☐ Other ☐ : ________________________________

6. **Education**: High-school diploma ☐ College Diploma/Degree ☐ University Degree ☐ Post-graduate Degree ☐ Other ☐ : __________________________________

☐ Arab	☐ European	☐ Indian	☐ Persian/Iranian
☐ African	☐ Filipino	☐ Japanese	☐ Sri Lankan
☐ Caribbean	☐ Hispanic	☐ Korean	☐ Vietnamese
☐ Chinese (including Hong Kong Chinese & Taiwanese)	☐ Indigenous (including First Nations, Inuit, Metis)	☐ Pakistani	☐ Other:

7. What is your ethnic background? Please mark all that apply.

8. What is your Primary language? _________________________

Appendix D – General Health Questionnaire

INSTRUCTIONS: The questions below concern your general health status and health-related behaviour. Although your responses will remain confidential, if you do not feel comfortable answering a question, please choose the "*prefer not to answer*" option. If you are not sure about an answer, please choose the "*do not know*" option.

Section One

The following segment asks about your experiences related to the COVID-19 pandemic.

1) Has a person close to you (a family member, or close friend) become sick because of COVID-19?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

2) Have you needed to self-isolate for 14 days (or more) during the pandemic?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

3) Have you felt burdened, or stressed because of COVID-related changes in your home life? For example, have you had to manage both childcare and work responsibilities because of school closures.

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

Section Two

The following segment asks about "long-term conditions", which have been *diagnosed by a health professional*. ("long-term conditions" are those expected to last, or that have already lasted, at least 6 months)

1) Do you have a respiratory disorder (e.g., asthma, chronic bronchitis, or emphysema)?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

2) Do you have a gastrointestinal disorder (e.g., gastritis, peptic ulcer, or irritable bowel syndrome)?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

3) Do you have a musculoskeletal disorder (e.g., hip pain, back pain, or hip pain)?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

4) Do you have hypertension (high blood pressure)?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

5) Do you have high blood cholesterol, or lipids?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

6) Do you have diabetes?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

7) Do you have a mood disorder such as depression, bipolar disorder, or dysthymia?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

8) Do you have an anxiety disorder such as obsessive-compulsive disorder, or post-traumatic stress syndrome?

Yes	☐	prefer not to answer	☐
No	☐	do not know	☐

Section Three

The following segment asks about the nature of your sleeping habits.

1) How long do you usually spend sleeping each night?

fewer than 4 hours	☐	more than 8 hours	☐
4 hours to 6 hours	☐	prefer not to answer	☐
6 hours to 8 hours	☐	do not know	☐

2) How often do you have trouble going to sleep, or staying asleep?

never	☐	all of the time	☐
sometimes	☐	prefer not to answer	☐
most of the time	☐	do not know	☐

3) How often do you feel “full of energy” in the morning?

never	☐	all of the time	☐
sometimes	☐	prefer not to answer	☐
most of the time	☐	do not know	☐

Section Four

The next segment asks about smoking-related behaviour.

1) Over the past month, did you smoke tobacco cigarettes every day, occasionally, or not at all?

daily	☐	not at all	☐	do not know	☐
occasionally	☐	prefer not to answer	☐		

2) During the past month, did you smoke any cigars, cigarillos, a pipe, or make use of a hookah every day, occasionally, or not at all?

daily	☐	not at all	☐	do not know	☐
occasionally	☐	prefer not to answer	☐		

3) In the past month, did you use an “e-cigarette” (also known as vaping) every day, occasionally, or not at all?

daily	☐	not at all	☐	do not know	☐
occasionally	☐	prefer not to answer	☐		

4) Within the past month, did you smoke cannabis (marijuana) cigarettes and/or use a cannabis vaporiser every day, occasionally, or not at all?

daily	☐	not at all	☐	do not know	☐
occasionally	☐	prefer not to answer	☐		

Section Five

The following set of questions asks about your alcohol consumption.

A "drink" refers to:
- a bottle, or small can of beer, cider or cooler with 5% alcohol content, or a small draft
- a glass of wine with 12% alcohol content
- a glass, or cocktail containing 1 oz of a spirit with 40% alcohol content

1) Over the past month, how often did you drink alcoholic beverages?

daily	☐	once during the month	☐
several times per week	☐	not at all	☐
once per week	☐	prefer not to answer	☐
a few times during the month	☐	do not know	☐

2) If you do drink alcohol, how many drinks would you typically consume on one occasion?

not applicable	☐	more than 5 drinks	☐
1 drink	☐	prefer not to answer	☐
2-3 drinks	☐	do not know	☐
4-5 drinks	☐		

Section Six

The next set of questions is about your use of various medications. The first question is about your use of various pain relievers. Most of these products will require a prescription, although some (for example, Tylenol #1) may be available without one.
We are not interested in pain relievers such as Advil.

1) During the past month, how often did you use a pain reliever (for either acute, or chronic pain)?

(for example, codeine products, like Tylenol #3, 292s, or 222s; oxycodone products, such as Percocet, or Percodan; other opioid products, such as hydromorphone, Dilaudid, or Demerol)

not at all	☐
daily	☐
once per week	☐
several times per week	☐
a few times during the month	☐
once during the month	☐
prefer not to answer	☐
do not know	☐

The next question concerns the use of various stimulants. By stimulants, we mean products prescribed by a doctor to help people who have attention, or concentration problems (such as ADHD). Examples of stimulants include Ritalin, Concerta, Adderall, and Dexedrine.

1) During the past month, how often did you use a stimulant?

not at all	☐
daily	☐
once per week	☐
several times per week	☐
a few times during the month	☐
once during the month	☐
prefer not to answer	☐
do not know	☐

The final question concerns your use of various sedatives, or anti-anxiety medications. By sedatives, we mean products that can be obtained from a doctor, such as diazepam, Valium, lorazepam, Ativan, alprazolam, Xanax, clonazepam, Rivotril. Sedatives are sometimes prescribed to help people sleep, calm down, or to relax their muscles.

1) During the past month, how often did you use a sedative?

not at all	☐
daily	☐
once per week	☐
several times per week	☐
a few times during the month	☐
once during the month	☐
prefer not to answer	☐
do not know	☐

Section Seven

The following questions ask about various types of physical activities that you would have done over a recent typical week. Please consider only those activities that you did for a minimum of 10 continuous minutes.

1) Weather permitting, in a typical week, about how frequently would you engage in activities like walking, or cycling to get to places such as work, or a shopping centre?

less than once/week	☐	daily	☐
1-2 times/week	☐	prefer not to answer	☐
3-4 times/week	☐	do not know	☐
5-6 times/week	☐		

2) Not including the activities reported above, in a typical week, how often would you participate in sports, fitness, or recreational physical activities (organised, or non-organised) that last a minimum of 10 continuous minutes?
Examples include walking, swimming, cycling, running, resistance training, and all team sports.

less than once/week	☐	daily	☐
1-2 times/week	☐	prefer not to answer	☐
3-4 times/week	☐	do not know	☐
5-6 times/week	☐		

3) In a typical week, how often would you complete any other physical activities while at work, in or around your home, or while volunteering? Examples include carrying heavy loads, shoveling, and household chores such as washing windows. Please remember to only include activities that lasted a minimum of 10 continuous minutes.

less than once/week	☐	daily	☐
1-2 times/week	☐	prefer not to answer	☐
3-4 times/week	☐	do not know	☐
5-6 times/week	☐		

4) In a typical week, approximately how long would you be involved in physical activities, such as those described in the previous questions?

fewer than 150 minutes	☐	prefer not to answer	☐
150 to 300 minutes	☐	do not know	☐
more than 300 minutes	☐		

Appendix E – The Multidimensional Scale of Perceived Social Support (MS-PSS)

INSTRUCTIONS: This form asks you about the support you receive from your partner, family, and friends. For each statement, think back over the past 6 months and indicate how much you disagree, or agree.

	DURING THE PAST 6 MONTHS…	Strongly Disagree 1	Disagree 2	Neither Agree nor Disagree 3	Agree 4	Strongly Agree 5
1.	My family really tried to help me.	O	O	O	O	O
2.	I got the emotional help and support I needed from my family.	O	O	O	O	O
3.	My friends really tried to help me.	O	O	O	O	O
4.	I could count on my friends when things went wrong.	O	O	O	O	O
5.	I could talk about my problems with my family.	O	O	O	O	O
6.	I had friends with whom I could share my joys and sorrows.	O	O	O	O	O
7.	My family was willing to help me make decisions.	O	O	O	O	O
8.	I could talk about my problems with my friends.	O	O	O	O	O

Appendix F – Social Support Scale for Firefighters (SSS-FF)

INSTRUCTIONS: This form asks you about the support you receive from firefighter co-workers. For each statement, think back over the past 6 months and indicate how much you disagree, or agree.

	DURING THE PAST 6 MONTHS…	Strongly Disagree 1	Disagree 2	Neither Agree, nor Disagree 3	Agree 4	Strongly Agree 5
1.	You were carefully listened to and understood by the firefighters you worked with.	O	O	O	O	O
2.	Among your firefighter colleagues, there was someone who made you feel better when you were feeling down.	O	O	O	O	O
3.	You had problems you could not discuss with other firefighters.	O	O	O	O	O
4.	Among your firefighter colleagues, there was someone you could go to when you needed advice.	O	O	O	O	O
5.	There were people in the fire service you could talk to about your experiences as a firefighter.	O	O	O	O	O
6.	The firefighters you knew respected the fact that you were a firefighter.	O	O	O	O	O
7.	You knew firefighters who would lend you money if you needed it.	O	O	O	O	O
8.	If you had been unable to do your daily chores at work, there was someone in the fire station who would have helped you with these tasks.	O	O	O	O	O
9.	If you had been ill, there were other firefighters who would have helped you.	O	O	O	O	O

Appendix G – The Perceived Stress Scale (PSS)

INSTRUCTIONS: This form asks you about your thoughts and feelings **during the last month**. In each case, circle *how often* you felt, or thought a certain way.

	DURING THE PAST MONTH…	**Never** 0	**Almost Never** 1	**Sometimes** 2	**Fairly Often** 3	**Very Often** 4
1.	How often have you been upset because of something that happened unexpectedly?	O	O	O	O	O
2.	How often have you felt that you were unable to control the important things in your life?	O	O	O	O	O
3.	How often have you felt nervous and “stressed”?	O	O	O	O	O
4.	How often have you felt confident about your ability to handle personal problems?	O	O	O	O	O
5.	How often have you felt that things were going your way?	O	O	O	O	O
6.	How often have you found that you could not cope with all the things that you had to do?	O	O	O	O	O
7.	How often have you been able to control irritations in your life?	O	O	O	O	O
8.	How often have you felt that you were on top of things?	O	O	O	O	O
9.	How often have you been angered because of things that were outside of your control?	O	O	O	O	O
10.	How often have you felt difficulties were piling up so high that you could not overcome them?	O	O	O	O	O

Appendix H – The Sources of Occupational Stress Scale (SOOS-14)

INSTRUCTIONS: Please indicate how bothered you have felt about the following sources of on-the-job stress **during the last 10 shifts** you worked.

	DURING THE LAST 10 SHIFTS, I HAVE FELT…	**Not Bothered**	**Somewhat Bothered**	**Extremely Bothered**
1.	Concerned about having a poor diet.	O	O	O
2.	Discrimination based on gender, ethnicity, or age.	O	O	O
3.	Exposure to an anxious, or overly demanding coworker, or administrator.	O	O	O
4.	Financial strain due to inadequate pay.	O	O	O
5.	Bothered by not being able to predict, or control events.	O	O	O
6.	Concern about not knowing the latest technology.	O	O	O
7.	Thoughts about past run(s) that have been particularly upsetting/disturbing.	O	O	O
8.	The negative effects of observing stress on coworkers. (for example, illness, alcohol abuse, or burnout)	O	O	O
9.	Dislike of routine paper work.	O	O	O
10.	Bothered by working with a substandard co-employee on emergency incidents, or situations.	O	O	O
11.	Conflicts with coworkers and team members.	O	O	O
12.	My sleep has been disrupted.	O	O	O
13.	Feelings of isolation from family due to work demands and stress.	O	O	O
14.	Concerns about serious personal injury, or death due to work.	O	O	O

Appendix I – Procedure for Data Collection

On any given day for data collection, the following procedures will be followed to ensure a standardized data collection process.

1. At the arrival of each participant, a brief information session about the proposed research will ensue. At this stage, the participant will be provided with the Information Letter and a consent form.
2. After having any questions/concerns addressed and signing the consent form, the first reading of the participant's blood pressure will be measured. NOTE: at this point, inquire whether the participant has consumed coffee, or engaged in exercise on the morning of the meeting.
3. After blood pressure measurement, each participant will be provided with a booklet that contains 6 distinct questionnaires. Completing the questionnaires will require 20-25 minutes. (participants will be given the option to ask questions, or raise concerns)
4. When the questionnaires are completed, a second blood pressure measurement will be taken, and the average of both measurements will be taken as the blood pressure reading.
5. After the blood pressure measurement, the following anthropometric data will be collected: weight, height, and hip circumference.
6. Next, heart rate variability will be measured. To ensure data is collected properly, the process will be explained and a small area of the chest may need to be shaved to permit proper electrode placement (the procedure will be discussed later).
7. Lastly, two biological samples (hair and blood) will be collected. The procedure will involve a preparatory phase that includes a brief explanation of the collection process.
8. When data collection is over, participants will be asked if they have any questions, or concerns, after which a feedback form containing contact information of the chief and primary investigator will be provided.

Blood Pressure Measurement

- Blood pressure (mmHg) data will be analyzed using the average of two readings obtained with participants in a seated position and measurement taken from the right arm using a standard sphygmomanometer.
- The first reading will be taken following the signing of the consent form and the second will be completed following completion of the questionnaire booklet.

- Further instruction on use of the OMRON blood pressure monitor can be found in its manual.

Anthropometric Data Measurement

- Body Mass Index (BMI; weight in kilograms/height in meters^2) will be assessed with participants in light clothing (no shoes, or jewelry).
- Weight will be measured using a standard weight measuring scale.
- Standing height will be measured to the nearest 0.1cm using a free-standing stadiometer.
- Waist circumference (WC; centimeters) will be measured horizontally at the midway point along the smallest circumference between the lowest ribs and iliac crest.
- To determine the waist to height ratio (WHtR), a simple division of the WC over height will be done.

Heart Rate Variability (HRV) Measurement

- Heart rate variability will be measured with ECG readings using the Bittium Faros device.
- The process includes proper skin preparation of the chest area, which might involve shaving chest hairs to make the 3 points for electrode placement accessible.
- The electrodes will be placed on both sides beneath the midpoint of the clavicle and one at the apex of the heart (5th intercostal space).
- After placing the electrodes, the Bittium Faros device will be mounted on the right side beneath the clavicle and the device activated to read for a standard period of 5 minutes.
- Participants will be in a seated position, with knees at a 90° angle, hands on thighs, palms facing upward, eyes closed.
- The HRV data will then be interpreted using the root-mean square differences of successive R-R intervals (RMSSD) on the Cardiscope Software.

Blood Sample Collection

- Due to the nature of this exercise, blood drawing will be handled exclusively by the primary investigator with aid from the RAs.
- The process will follow a strict Standard Operating Procedure that has received ethics clearance.
- Excerpts from the SOP are provided:

1. The research associate informs the participant that the procedure is most commonly performed on the ring finger of the non-dominant hand in order to minimise interference with daily routines, and then asks the participant which finger they would prefer to use.
2. Participants may be asked to keep their hands below the waist and/or massage their fingers to increase local blood flow.
3. The finger identified by the participant is disinfected with an alcohol wipe and allowed to dry.
4. Blood samples are collected with a single-use safety lancet. To take the sample, the research associate describes that the participant will need to puncture the fleshy part of the finger pad approximately 1 cm from the tip of the finger at the mid-point between the sides of the finger.
5. The first blood sample is wiped away with cotton. The subsequent blood sample is collected onto a pipette and then a paper test strip.
6. Upon completion of the blood draw, cotton is pressed on the fingertip and the participant is asked to sit still and apply pressure to stop bleeding and reduce the risk of bruising.
7. The lancet will then be disposed into the sharp disposal container.
8. Once the bleeding has subsided, or stopped, a bandage is applied over the puncture, and the participant is asked to sit quietly for up to 10 minutes.
9. The research associate informs the participant that bruising may be present at the site of the puncture over the following days, and that the participant should keep the area clean and dry to promote healing.
10. The participant is thanked for their participation.

Hair Sample Collection

- On the day of sample collection, the hair cortisol analysis method will be briefly described to each participant (e.g., site of hair collection, the hormone of interest, and hair storage will be discussed). Questions and concerns regarding the sampling method will be addressed before the start of the process.
- In consideration of the different ethnicities of participants, a culturally sensitive approach will be prioritized.
- A small sample (about 10 g) will be taken, with a focus on approximately the first 3 cm of the hair shaft (given that hair grows at an average rate of 1cm/month, the sample should provide information on cortisol levels during the preceding 3 months).
- Collected hair samples will then be labelled with participant's ID and put inside an envelope and kept in storage.

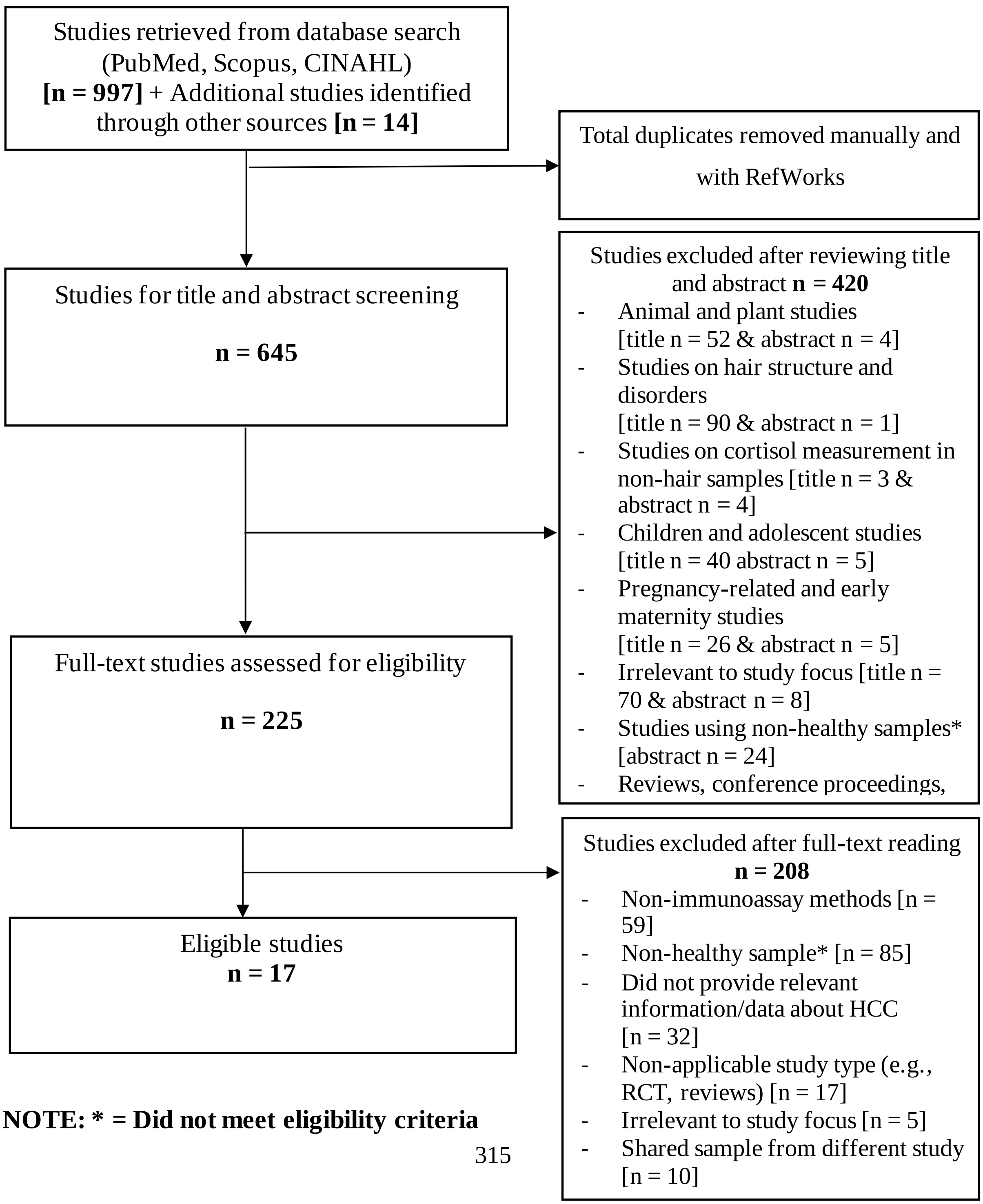
Appendix J – Database search strategy used for the systematic review and analysis (chapter 5: study 2)

PUBMED **((((((((("hair cortisol") OR ("scalp hair cortisol")) OR ("hair cort*")) OR ("cortisol in hair")) NOT (adolescents))) NOT (child*)) NOT (preschoolers)) NOT (infants)) NOT (newborns)) NOT (pregnan*) Filters: Humans, English** https://pubmed-ncbi-nlm-nih-gov.proxy.lib.uwaterloo.ca/rss/search/1raUxiGThRUZ-m6Org6B50GZycHiXVtxD3-2mi5Xp8IsQoaouF/?limit=15&utm_campaign=pubmed-2&fc=20200616165636 Filters: Human; English
Articles retrieved: 321

SCOPUS: ("hair cortisol" OR "scalp hair cortisol" OR "hair cort*" OR "cortisol in hair" OR "hair glucocorticoid(s)") AND NOT adolescents AND NOT child* AND NOT preschoolers AND NOT infants AND NOT newborns AND NOT "pregnant*" AND NOT animal* Limit to: English
Articles retrieved: 481

CINAHL: ("hair cortisol" OR "scalp hair cortisol" OR "hair cort*" OR "cortisol in hair" OR "hair glucocorticoid(s)") OR "hair cortisol concentration" NOT child* NOT preschoolers NOT (infants OR baby OR newborns OR neonate) NOT (adolescents OR teenagers) Filter: English
Articles retrieved: 195

Appendix K – Flow chart for study identification and screening of the systematic review and analysis (chapter 5: study 2)



NOTE: * = Did not meet eligibility criteria

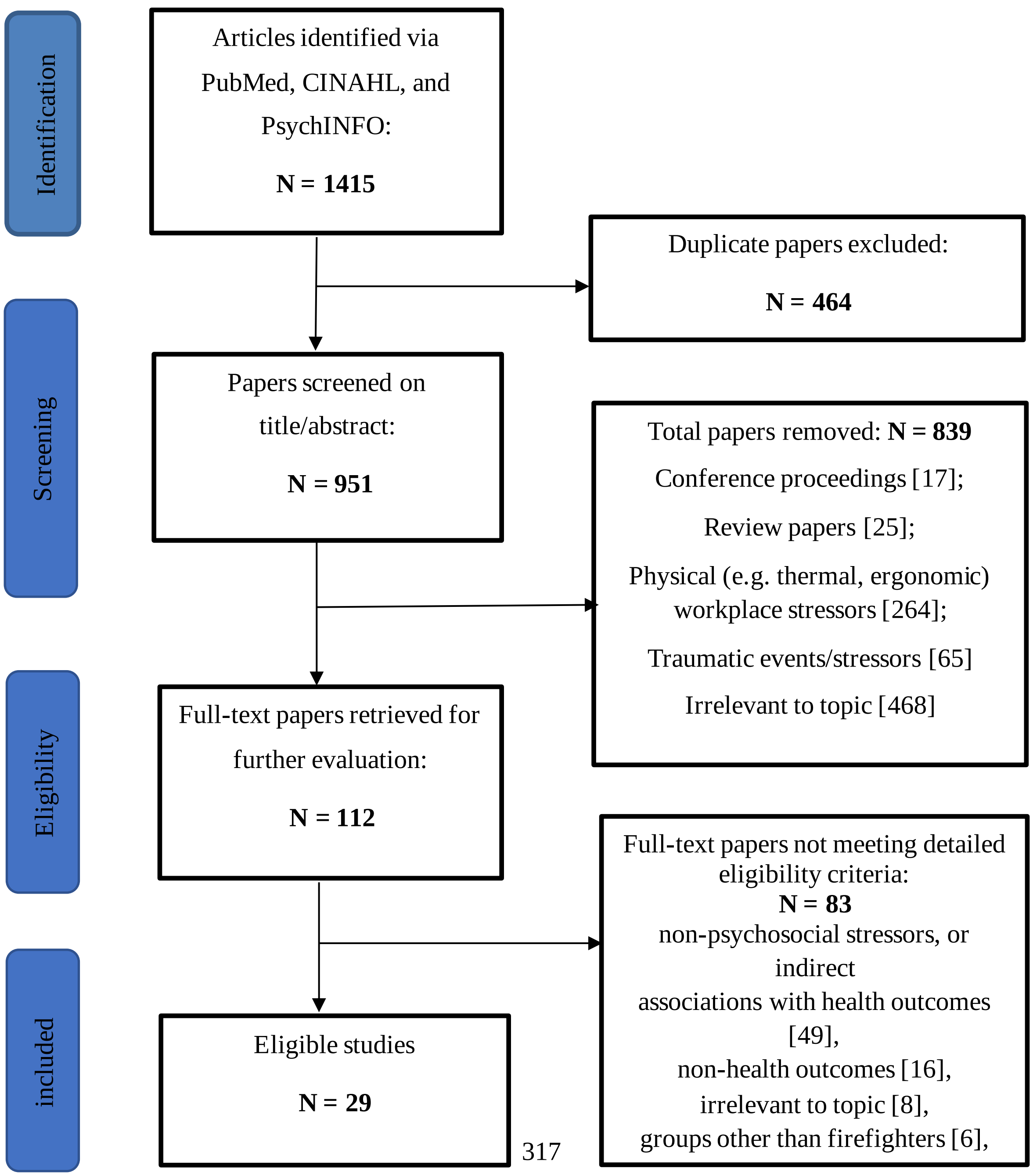
Appendix L – Database search strategies developed for the systematic review (chapter 6: study 3)

Database: PUBMED (firefighter OR firefighters OR firefighting OR fire-fighter OR "fire fighter" OR fireman OR "fire service") AND ("psychosocial stress" OR "psychosocial stressors" OR stress OR stressors) **Filters:** Humans, English Filters: Human, English
Search results: 553

Database: CINAHL (Firefighter* OR firefighting OR fire-fighter OR "fire fighter" OR fireman OR "fire service") AND ("psychosocial stress" OR "psychosocial stress" OR stress OR stressors) Filters: English, Academic articles
Search result: 367

Database: PsycInfo Firefighter* OR firefighting OR fire-fighter OR "fire fighter" OR fireman OR "fire service") AND ("psychosocial stress" OR "psychosocial stress" OR stress OR stressors Filters: Journal
Search result: 495

Appendix M - Flow chart for study identification and screening for the systematic review (chapter 6: study 3)



Appendix N

SPSS syntax for study 4 (chapter 7)

SPSS Syntax for chapter 7

```
DATASET ACTIVATE DataSet2.
FREQUENCIES VARIABLES=Age LOS SBP DBP BMI WHR HbA1c HDL LDL HRV
cortisol MSPSS SSSFF SOOS PSS
  /FORMAT=NOTABLE
  /NTILES=4
  /STATISTICS=STDDEV RANGE MINIMUM MAXIMUM MEAN SKEWNESS SESKEW
KURTOSIS SEKURT
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=Gender Smoking Exercise Alcoholintakefrequency
SleepHrs
  /STATISTICS=MEAN
  /ORDER=ANALYSIS.

T-TEST GROUPS=Gender(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=MSPSS SSSFF SOOS PSS ALI
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

T-TEST GROUPS=Exercise(0 1)
  /MISSING=ANALYSIS
  /VARIABLES=MSPSS SSSFF SOOS PSS ALI
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

ONEWAY MSPSS SSSFF SOOS PSS ALI BY Alcoholintakefrequency
  /ES=OVERALL
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY MSPSS SSSFF SOOS PSS ALI BY SleepHrs
  /ES=OVERALL
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

CORRELATIONS
  /VARIABLES=Age LOS SBP DBP BMI WHR HbA1c HDL LDL HRV cortisol
MSPSS SSSFF SOOS PSS ALI Cort_log
```

```
    HbA1c_log HRV_log
  /PRINT=TWOTAIL NOSIG FULL
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.
```

REGRESSION

```
  /DESCRIPTIVES MEAN STDDEV CORR SIG N
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA COLLIN TOL CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT ALI
  /METHOD=ENTER SOOS PSS
  /METHOD=ENTER Age LOS
  /METHOD=ENTER MSPSS SSSFF.
```

Appendix O

SPSS syntax and R codes for study 5 (chapter 8)

SPSS Syntax for univariate and bivariate analysis for Chapter 8

```
DATA: Firefighter data, phases 1&2 (Full-case analysis)
Psychometric analysis for scale measures

DATASET ACTIVATE DataSet1.
RELIABILITY
  /VARIABLES=Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9
  /SCALE('SSS-FF') ALL
  /MODEL=ALPHA
  /STATISTICS=DESCRIPTIVE SCALE CORR
  /SUMMARY=MEANS.

DATASET ACTIVATE DataSet2.
RELIABILITY
  /VARIABLES=QI Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10 Q11 Q12 Q13 Q14
  /SCALE('SOOS-14') ALL
  /MODEL=ALPHA.

DATASET ACTIVATE DataSet3.
RELIABILITY
  /VARIABLES=Q1 Q2 Q3 Q4 Q5 Q6 Q7 Q8 Q9 Q10
  /SCALE('PSS-10') ALL
  /MODEL=ALPHA
  /STATISTICS=DESCRIPTIVE SCALE
  /SUMMARY=MEANS.
```

UNIVARIATE

```
DATASET ACTIVATE DataSet1.

FREQUENCIES VARIABLES=Age1 LOS1 SBP1 DBP1 WHR1 HbA1c1 HDL1 LDL1 HRV1

Cort1 SSSFF1 SOOS1 PSS1

  /FORMAT=NOTABLE
  /NTILES=4
  /STATISTICS=STDDEV VARIANCE MINIMUM MAXIMUM MEAN SKEWNESS SESKEW
KURTOSIS SEKURT
  /ORDER=ANALYSIS.

FREQUENCIES VARIABLES=SBP2 DBP2 WHR2 HbA1c2 HDL2 LDL2 HRV2 Cort2
  /FORMAT=NOTABLE
```

```
  /NTILES=4
  /STATISTICS=STDDEV VARIANCE MINIMUM MAXIMUM MEAN SKEWNESS SESKEW
KURTOSIS SEKURT
  /ORDER=ANALYSIS.

DATASET ACTIVATE DataSet1.
FREQUENCIES VARIABLES=sex Rank2 Education1 Rel.Status2 Covid19
MariJuanause2 Exercise2 Smoking1 AIF
    Sleep1 RankC
  /ORDER=ANALYSIS.
```

BIVARIATE

```
CORRELATIONS
  /VARIABLES=Age1 LOS2 SBP1 SBP2 DBP1 DBP2 WHR1 WHR2 HbA1c1 HbA1c2
HDL1 HDL2 LDL1 LDL2 HRV1 HRV2
    Cort1 Cort2
  /PRINT=TWOTAIL NOSIG FULL
  /STATISTICS DESCRIPTIVES
  /MISSING=PAIRWISE.

T-TEST GROUPS=sex(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=ALI1 ALI2
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

T-TEST GROUPS=Covid19(0 1)
  /MISSING=ANALYSIS
  /VARIABLES=ALI1 ALI2
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

T-TEST GROUPS=MariJuanause2(0 1)
  /MISSING=ANALYSIS
  /VARIABLES=ALI1 ALI2
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

T-TEST GROUPS=Smoking1(0 1)
  /MISSING=ANALYSIS
  /VARIABLES=ALI1 ALI2
  /ES DISPLAY(TRUE)
  /CRITERIA=CI(.95).

ONEWAY ALI1 ALI2 BY Education1
```

```
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY ALI1 ALI2 BY Rel.Status2
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY ALI1 ALI2 BY Exercise2
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY ALI1 ALI2 BY AIF
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY ALI1 ALI2 BY Sleep1
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).

ONEWAY ALI1 ALI2 BY RankC
  /ES=OVERALL
  /STATISTICS DESCRIPTIVES EFFECTS
  /MISSING ANALYSIS
  /CRITERIA=CILEVEL(0.95).
```

LINEAR MIXED MODELS

```
library(readxl)
library(nlme)
library(lme4)
library(lattice)
library(tidyverse)
library(sjPlot)
install.packages("psychometric")
```

```
#outcome variable = ALI
#predictors = PSS, SOOS, TIME
#confounder = C19, Age, Social support
```

#unconditional means model

```
# No predictor in the model (no independent variables)
# This is the null model (Beginning of the intercept only)
# Time is not being measured within this model
# measuring the grand mean here
#can we reject the Null hypothesis that the grand mean for the
intercept is equal to zero?
#run unconditional means model with summary - using ID as he random
effect

#In the Mod1 model, all FF are nested within themselves. No slope
yet.

Mod1<-lme(ALI~1,random = ~1|ID, data = FDL4, method = "ML")
summary(Mod1)
VarCorr(Mod1)
#FINDINGS
# The Loglik shows the model has a value.
# for the fixed effect, the grand mean is 1.78, with pvalue of 0, it
significantly differs from zero
# Hence, we reject the null model that the intercept does not differ
from zero


#calculate the intra-class correlation (ICC) for the unconditional
means model
#ID
(1.1211997^2)/((1.1211997^2) + (0.9668416^2)) #correct this!

#OR use the ICC!.lme function in Psychometric package
library(psychometric)
ICC1.lme(ALI,ID,data = FDL4)
# Note any value above 0.05 suggests clustering is taking place
# ICC = 0.5808512
# larger ICC values indicate greater clustering is taking place
# our ICC value justifies the need for multilevel modelling

# run intervals for the unconditional means model (Mod1)
intervals(Mod1)
```

```
# The random effects is significant indicating a significant
individual variability and there's much to variability within our
model

#using the "Lme4" function to confirm
library(lme4)
attach(FDL4)
Med <-lmer(ALI ~ 1 + (1|ID),data = FDL4,REML = FALSE)
summary(Med)


#Model 2
# Unconditional Growth model (setting up the slope)
# is TIME (different data collection phase) best represented as a
fixed or a random slope?
# Begin plotting the data to see individual slope

library(lattice)
xyplot(ALI ~ TIME|ID, data = FDL4, type = c("p", "r"))
```

 # run the unconditional growth model

```
# unconditional growth model (Mod2) - TIME as a fixed slope
#Mod2 <-lme(ALI ~ TIME, random = ~ 1|ID, data = FDL4)
Mod2 <-lme(ALI~ TIME, random = ~ 1|ID, data = FDL4, method = "ML")
summary (Mod2)
intervals(Mod2)

# Time as a fixed slope is not significant

#Model 3
#unconditional means model(mod4) - Time as a random slope
Mod4<-lme(ALI ~ TIME,random = ~TIME|ID, data = FDL4, method = "ML")
summary(Mod4)
VarCorr(Mod4)
intervals(Mod4)

# However, Time as a random effect was significant.


#compare unconditional growth model (mod2) to unconditional growth
model with random slope (mod2)
(results <- anova(Mod2,Mod4))
results$'p-value'

#Using ML, compare both ICC
```

```
#repeat process but use ML rather than REML

# This means that once we have included a random slope , the
clustering has gone up higher. Hence a random slope addressed more
of the clustering.
#based on log like values and deviant statistics
```

 # Conditional Growth Model (full Model)

```
#adding level 1 predictors
mod5<-lme(ALI~TIME + PSS + SOOS, random = ~ TIME|ID, data = FDL4,
method = "ML")
summary(mod5)
tab_model(mod5)
VarCorr(mod5)
intervals(mod5)

#adding level 2 predictors
mod6<-lme(ALI~TIME + PSS + SOOS + Age1  + SSSFF1, random = ~
TIME|ID, data = FDL4, method = "ML")
summary(mod6)
tab_model(mod6)
VarCorr(mod6)
intervals(mod6)

#adding level 3 predictors
mod7<-lme(ALI~TIME + C19 + PSS + SOOS + SSSFF1 + Age1, random = ~
TIME|ID, data = FDL4, method = "ML")
summary(mod7)
tab_model(mod7)
intervals(mod7)
VarCorr(mod7)
```