An Examination of the Relationship Between Persistent Traumatic Brain Injuries and Chronic Pain Conditions in Active-Duty and Veteran Soldiers: Results from the Canadian Armed Forces Members and Veterans Mental Health Follow-up Survey

by

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Dedication

To my family and friends, thank you for being my cheerleaders throughout this journey. Aaron, thank you for your constant support, encouragement, and patience. Luca, thank you for being the best source of inspiration and distraction.

Abstract

Traumatic brain injuries (TBI) are highly prevalent among military personnel. TBIs have been shown to be associated with lasting negative physical health, mental health, and psychosocial consequences. Chronic pain is one common comorbidity for those experiencing persistent effects of a TBI. This study examined the relationship between persistent TBI and chronic pain conditions (i.e., arthritis, back problems, gastrointestinal conditions, and migraine headaches) in a Canadian military sample, including potential preinjury characteristics (i.e., sociodemographic and military demographics), mental health disorders (e.g., depression, PTSD) and other biopsychosocial factors (i.e., social support, sleep difficulty), as well as potential moderators (i.e., sex and serving status) that impact this relationship. This study utilized data from the Canadian Armed Forces Members and Veterans Mental Health Follow-up Survey (CAFMVHS) collected in 2018 (n = 2,941). Logistic regression analyses demonstrated arthritis, back problems, migraine headaches, and gastrointestinal conditions to be significantly associated with persistent TBI. Preinjury characteristics (i.e., sociodemographic, and military demographics) associated with comorbid persistent TBI and any chronic pain condition(s) included military rank and serving status. The comorbidity of any mental health disorders was not significantly more associated with persistent TBI and any chronic pain condition(s). Biopsychosocial factors associated with comorbid persistent TBI, and any chronic pain condition(s) included problem-solving coping and sleep difficulties. Findings identify the prevalence of chronic pain conditions among CAF members with persistent TBI and provide further insight potential risk factors that may influence this relationship including military characteristics, mental health disorders, and other biopsychosocial factors.

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An Examination of the Relationship Between Persistent Traumatic Brain Injuries and Chronic Pain Conditions in Active-Duty and Veteran Soldiers: Results from the Canadian Armed Forces Members and Veterans Mental Health Follow-up Survey

Chapter 1: Introduction & Literature Review

Traumatic Brain Injuries

Traumatic brain injuries (TBI) are defined as the result of an external force causing notable changes in brain activity, function, and/or structure(s) (Menon et al., 2010). The worldwide prevalence of TBI has grown immensely over the past few decades, with a global estimate of over 50 million individuals experiencing a TBI every year (Dams-O'Connor et al., 2023). The severity classification used to predict patient outcomes following a TBI include mild, moderate, and severe cases. Mild TBIs, while considered the least severe classification, are among the most common neurological injuries experienced, representing a significant burden on the affected individuals, their families, and the healthcare system (Grandhi et al., 2017; Mollayeva et al., 2018). However, caution in using TBI classifications are warranted as these have commonly been based on patient outcomes immediately following injury and, as such, provide a limited indication toward long-term outcomes (Bosco et al., 2013). Disruptions to structural brain connectivity and more difficult to see changes in brain networks can vary greatly by individual, including those who experience mild cases of TBI (Bhattrai et al., 2019). Moreover, there is a high degree of heterogeneity in how TBIs present across individuals, making this a difficult condition to predictably diagnose, classify, and treat. Recovery is further complicated by individual differences in brain functionality and neuroplasticity (Bosco et al., 2013). TBI has historically been identified and treated as an isolated injury that follows an expected timeline, where a majority of individuals' symptoms resolve within weeks of the injury (Déry et al., 2021; Polinder et al., 2018). However, there has been a major shift in both the research and clinical literature surrounding TBI, resulting in a growing acceptance of recognizing and treating TBI as a chronic and dynamic condition (Dams-O'Connor et al., 2023; Kumar et al., 2022).

There is no consistent or predictable trajectory that individuals follow after a TBI; post-TBI symptoms can present as highly variable and are influenced by a myriad of preinjury and

other moderating and/or mediating factors (Polinder et al., 2018). TBI has been shown to be associated with cognitive impairments (e.g., memory and concentration), behavioural problems (e.g., disinhibition), physiological consequences (e.g., headache, fatigue) and psychological effects (e.g., depression, suicidality) (Déry et al., 2021; Kanefsky et al., 2019; Kumar et al., 2022). While many individuals recover from TBI symptoms within a couple of weeks, recent literature demonstrates that a growing number of individuals experience ongoing symptoms, which have been referred to as post-concussive symptoms (Bosco et al., 2013; Garber et al., 2016; Polinder et al., 2018). Although more severe cases of TBI often result in worsened and prolonged adverse symptoms, roughly 10-25% of individuals with mild TBI continue to experience lasting negative impairments (Déry et al., 2021). Some of the most common ongoing symptoms experienced include headaches, fatigue, and problems with memory and concentration (Grandhi et al., 2017; Kumar et al., 2022; Silverberg et al., 2020). The symptom profile of long-term TBI is further complicated by the overlap of symptoms commonly observed in other comorbid disorders, such as posttraumatic stress disorder (PTSD) and depression, making any recognized symptom profile highly controversial (Howlett et al., 2022; Polinder et al., 2018).

Those experiencing persistent effects of TBI have been shown to have slower recoveries, decreased quality of life, increased psychological dysfunction, higher likelihood of physiological conditions, and a heightened prevalence of suicidality and mortality (Gause et al., 2017; Grandhi et al., 2017; Polinder et al., 2018). One of the most common long-term comorbidities associated with TBI is chronic pain.

Chronic Pain Conditions

Pain is recognized and defined as a chronic condition when it lasts for 3-6 months or longer and includes persistent or recurrent forms of pain (Treede et al., 2015). Chronic pain is described as being distinct from acute pain, which dissipates after a number of weeks, and instead is an ongoing pain that can last years; classified as nociceptive, neuropathic or mixed pain (Irvine & David Clark, 2018; Mehalick & Glueck, 2018). Furthermore, chronic pain is maintained through factors not associated with the initial cause and can include biological, physiological, psychological, or social-related factors that act to perpetuate the pain (Mills et al., 2019; Raffaeli et al., 2021).

Globally, chronic pain has been implicated as the leading cause of overall disability and burden (Mills et al., 2019). Among the most common chronic pain conditions are tension-focused or migraine headaches, back pain, and osteoarthritis (Cohen et al., 2021; Mills et al., 2019). Gastrointestinal conditions including irritable bowel disease, irritable bowel syndrome, ulcers and colitis have similarly been characterized by chronic features, including abdominal pain (Drewes et al., 2020; Kolacz & Porges, 2018). Chronic pain symptom profiles, like those of TBI, can be highly complex, nuanced, and heterogeneous across individuals, making diagnoses difficult to get right – or for an individual to get at all. The implications of chronic pain are likewise far reaching and have been associated with a diminished general well-being; difficulties with employment, daily activities, and relationships; an increased use of healthcare utilization, and a shortened life expectancy (Clauw et al., 2019; Cohen et al., 2021). Psychological symptoms, along with sleep difficulties, are among the most frequent co-morbidities associated with chronic pain conditions (Meints & Edwards, 2018). Past research findings have suggested that mental health symptoms and increased stress have been shown to increase the chances of individuals transitioning from acute pain into chronic pain (Meints & Edwards, 2018).

The highly nuanced nature of chronic pain conditions makes treatment and management of pain an often drawn out and unsuccessful endeavor. Further complicating the understanding, diagnosing, and management of chronic pain conditions are the pre-existing conditions or injuries one may have. Chronic pain conditions can often be related to a specific injury event; however, they can also be the outcome of a series of events. One such event that has been shown to be highly associated with chronic pain outcomes, and a major contributor to complicated recovery, is TBIs (Chen et al., 2023; Hammond et al., 2019).

Traumatic Brain Injuries & Chronic Pain Conditions

Individuals with chronic pain and TBI have found this co-occurrent relationship to severely interfere with their ability to function socially and occupationally, which can lead to increased negative mental and physical comorbidities, which can in turn further influence the presence and intensity of their chronic pain (Otis et al., 2011). While current literature provides evidence supporting an association between TBI and chronic pain, where the two are found to occur simultaneously (Bosco et al., 2013), the nature of this association has conflicting theories.

Some past reviews have suggested that chronic pain can be the result of a TBI-injury and may be independent of mental disorders or other factors (Bosco et al., 2013; Grandhi et al., 2017; Nampiaparampil, 2008). For example, in a large representative study of U.S. soldiers, chronic headaches remained significantly associated with TBI after adjusting for mental disorders (Hoge et al., 2008). However, others have suggested, based on their findings, that the development of pain among those with mild TBI is due to the indirect effects of other factors – for example a PTSD diagnosis (Hoot et al., 2018). While alternative opinions within the literature fall somewhere in between, agreeing that an independent relationship exists between TBI and chronic pain, the association is believed to be partially mediated and/or moderated by the presence of co-occurring mental health disorders, particularly depression and PTSD (Irvine & David Clark, 2018; Seal et al., 2017). The presence of TBI, PTSD, and chronic pain in particular has been deemed the ‘polytrauma clinical triad’, where evidence supports the co-occurrence of all three together more often than observing the occurrence of any one of those conditions alone (Gauntlett-Gilbert & Wilson, 2013; Mehalick & Glueck, 2018; Schoneboom et al., 2016). In one retrospective cohort study of American veterans, the authors demonstrated that it was the combination of TBI, depression, and PTSD that had the strongest association with chronic pain and, therefore, the highest risk of chronic pain development compared to each condition independently (Seal et al., 2017).

There are few studies that have examined the broader relationship between persistent TBI and chronic pain conditions, including the examination into potential moderators. While mental health disorders, specifically anxiety disorders, depression, and PTSD have been suggested to be related to the development of chronic pain among those with TBI (Mollayeva et al., 2017; Nampiaparampil, 2008; Seal et al., 2017), they have also been established as comorbid outcomes that didn’t exist before injury (Howlett et al., 2022). Other potentially associated factors to the relationship between TBI and chronic pain condition outcomes may include the increased use of negative coping strategies, sleep disorders, moral injuries, and substance use disorders, as these have been suggested or implicated in past reviews and studies (Blakey et al., 2018; Hinkel et al., 2022; Nampiaparampil, 2008; Otis et al., 2011; Seal et al., 2017).

Traumatic Brain Injuries and Chronic Pain Conditions in the Military

One of the populations most vulnerable to the development of TBI is military personnel, due to their high-risk occupations. Injuries resulting in TBI among military personnel most commonly occur during warfare due to heightened exposure to violent impacts from combat and shock waves from blast injuries (Elder et al., 2019; Garber et al., 2014; Kanefsky et al., 2019; Kong et al., 2022). Important to note, TBIs can also occur outside of deployment settings and may be the result of injury during training (Escolas et al., 2020). The burden associated with TBI within the military context creates additional challenges, including longer delays from work, higher volumes of members transitioning out of service, increased suicidality, and a staggering increase in healthcare utilization and cost in comparison to the general population (Blakey et al., 2018; Hoot et al., 2018; MacGregor et al., 2023; Schafer et al., 2023).

The overall prevalence of TBI among military personnel has ranged from 10% to 90% in past literature (Khoury & Benavides, 2018; Mehalick & Glueck, 2018; Nampiaparampil, 2008). This large range is the result of inconsistencies in TBI reporting and a lack of clear definitions. A recent review of military TBIs noted TBI estimates in the military have also varied greatly by country, with the U.S. reporting an incidence of mild TBI between 15.2-22.8% for those returning from deployments to Iraq and Afghanistan, while in the UK and Canada, the reports of mild TBI among those returning from Afghanistan were 4.4% and 5.2% respectively (Kong et al., 2022). In a Canadian cross-sectional study, approximately 10-20% of personnel returning from recent conflicts such as Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) experienced a TBI (Vartanian et al., 2022). Moreover, it has been estimated that 10-15% of blast- or impact-related TBIs experienced by active-duty and veteran military members become chronic, with these individuals experiencing long-lasting adverse symptoms (Aldag et al., 2017).

The overall prevalence of chronic pain among military personnel is disproportional to that of civilians. In a recent review, the authors provided an estimated point prevalence of 20.4% for the general U.S. population and noted higher prevalences have been shown for military personnel (Cohen et al., 2021). Another review described a rate of 44% amongst U.S. military members who had been deployed in comparison to 26% in the general population (Schoneboom et al., 2016). Similar findings have been noted among CAF members and veterans. In a large representative study of active-duty CAF members, the prevalence of chronic pain was roughly

25% among respondents (Vun et al., 2018), while CAF veterans have been shown to have a prevalence of chronic pain nearly twice what has been observed among the general population, 41% vs. 22% respectively (Thompson et al., 2020; Veterans Affairs Canada, 2019). Additional studies have noted a similar trend, with CAF veterans showing a higher prevalence of conditions typically associated with chronic pain, including arthritis, back pain, migraines, and gastrointestinal conditions, when compared to the general population (Gironda et al., 2006; Perera et al., 2021; Thompson et al., 2020).

The heightened prevalence of TBI and chronic pain among military populations can likewise be seen when the two conditions occur together. Chronic pain and TBI are among the most common concerns and diagnoses of military members returning from OEF/OIF (Bosco et al., 2013). Among returning soldiers and veterans with deployment-related TBI, pain has been endorsed by an estimated 30-90%, with headaches being the most frequently noted chronic pain condition (Mehalick & Glueck, 2018; Nampiaparampil, 2008). Chronic post-traumatic headaches, a secondary headache classification, is associated with injuries like TBI and may be misdiagnosed as chronic migraine headaches due to similar clinical phenotypes (Kung et al., 2023; Maleki et al., 2021). An overall pooled prevalence of chronic headaches among civilians with TBI has been estimated to be approximately 44.3% at three months post-injury (Herrero Babiloni, Bouferguene, et al., 2023). However, the prevalence of chronic headaches has been demonstrated to be substantially lower in a sample of veterans with mild TBIs (Maleki et al., 2021). In a recent review on chronic pain among service members and veterans with TBI, back pain followed headaches as the most prevalent chronic pain conditions, with a prevalence estimate ranging between 32-44% (O'Neil et al., 2020). Arthritis has been shown to have nearly double the prevalence among U.S. veterans who recently returned from deployment with mild TBIs in comparison to those without TBI, 43% vs. 28% respectively (Hoot et al., 2018). Additionally, gastrointestinal conditions have been commonly reported among U.S. veterans experiencing chronic pain, including among those with TBI (Hinkel et al., 2022); however, little is known regarding the prevalence of gastrointestinal conditions among those with TBI in both military and civilian populations.

Over the past few decades, studying TBI has become, and remains, a significant priority within the military due to its staggering prevalence and its impactful and lasting burden on active-duty members and veterans (Schafer et al., 2023). Advancements have been made in the

screening, evaluation, and treatment of TBI; however, there is still much unknown about the long-term (i.e., 3 months or longer) outcomes experienced among military members and veterans, especially within a Canadian context. Most studies on TBI and comorbid chronic pain have largely focused on American military populations, and most often with a focus on veterans seeking care. However, these findings do not represent all serving and released military members, particularly those who are not actively seeking treatment. Additionally, far fewer studies have brought attention to active-duty members, an important population that may experience a TBI and re-deploy. It is important to understand whether differences exist across outcomes (i.e., chronic pain conditions) between veteran and active serving members and how other diagnoses (i.e., mental health disorders) and biopsychosocial factors (e.g., coping styles) are associated with this relationship.

To date, there have been no studies specifically examining the relationship between the long-term effects of TBI (i.e., persistent TBI) and chronic pain conditions among CAF members and veterans. Thus far, past studies on the CAF have largely observed the occurrence of TBI and chronic pain separately. There is a need to better understand the complex relationship between persistent TBI and chronic pain conditions and the factors that are associated with this relationship to prevent and mitigate long-term adverse outcomes, and to help inform and focus future research on this population. In elucidating this relationship, potential adaptations to assessing, treating, and intervening among CAF personnel may also provide an opportunity to keep more military personnel successfully within the CAF.

Conceptual Framework of TBI and Chronic Pain Condition(s)

There are numerous models and frameworks that have been proposed to examine the relationship between TBI and co-morbid conditions. Given the complexity of TBI - the individual preinjury risk factors, the nature of the injury itself, the diversity of acute and chronic symptoms post-injury, and the common post-injury co-morbid conditions, a biopsychosocial approach has been recommended for examining TBI and its relationship to chronic pain. Furthermore, the biopsychosocial model has become a well-regarded model for understanding the multidimensional and complex interactions of chronic pain among affected individuals (Cohen et al., 2021).

The biopsychosocial model was first coined by Dr. Engel in 1977 as a medical framework that emphasized taking into account a whole-person view of the individual, bringing attention to not only the biological factors, but the psychological, social, and cultural factors as well (Engel, 1997, 2012). Since then, the biopsychosocial model has been used to guide research in an effort to better understand an individual's post-TBI outcomes (Howlett et al., 2022). While this study will not directly use Engel's biopsychosocial model, it serves well as an introduction and foundation for the proposed framework.

The main advantage of using a biopsychosocial model in this study was that the focus was not on the injury incident alone, nor were the outcomes and potential associations only represented at a biological level. Instead, the focus was to understand the multitude of factors that may occur alongside the persistent TBI to influence the outcome of chronic pain conditions and the relationship between persistent TBI and chronic pain conditions. For instance, the chronic effects of TBI can have extensive consequences that impact one's social environment, including potential changes to their working status, disruptions to their interpersonal relationships, and challenges in coping with the stress of daily living (Grandhi et al., 2017). Impact is likewise present at a psychological level, with a high prevalence of co-morbid mental health disorders, increased substance abuse problems, and suicidality (Brenner et al., 2023; Faulkner et al., 2020). The adverse outcomes that occur at a social and psychological level interact with those at a biological level, for instance the temporary and lasting alterations in neurological functioning (Howlett et al., 2022). In the context of examining chronic pain, reciprocal influences have been described at the biological (e.g., nervous system, genetics), psychological (e.g., depression, fear, guilt), and social levels (i.e., support, working environment, access to care) (Canadian Pain Task Force, 2019; Cohen et al., 2021). Therefore, the biopsychosocial model was appropriate and well-suited for examining the relationship between persistent TBI and chronic pain conditions and could provide a more holistic view of an individual's trajectory post-injury, while accounting for a range of complex interactions and outcomes.

Polinder and colleagues (2018) adapted the biopsychosocial model for studying post-concussive symptoms experienced after a mild TBI from a previous model by Yeates and colleagues (2010), which was specific to children and adolescents. The models by Polinder et al. (2018) and Yeates et al. (2010) were largely used to outline a multidimensional approach to post-

concussive symptom analysis using a biopsychosocial lens. Figure 1 provides an example of the model by Polinder and colleagues, which demonstrates the variance occurring across the injury pathway, starting with preinjury factors, the injury itself, then moving into post-concussive symptoms, and the associated outcome of the individual, all while accounting for influencing effects from overlapping symptoms and post-injury factors. This model can be helpful in guiding research but can also be instrumental in clinical use, where it can help guide the screening and treatment of individuals with TBI (Yeates, 2010).

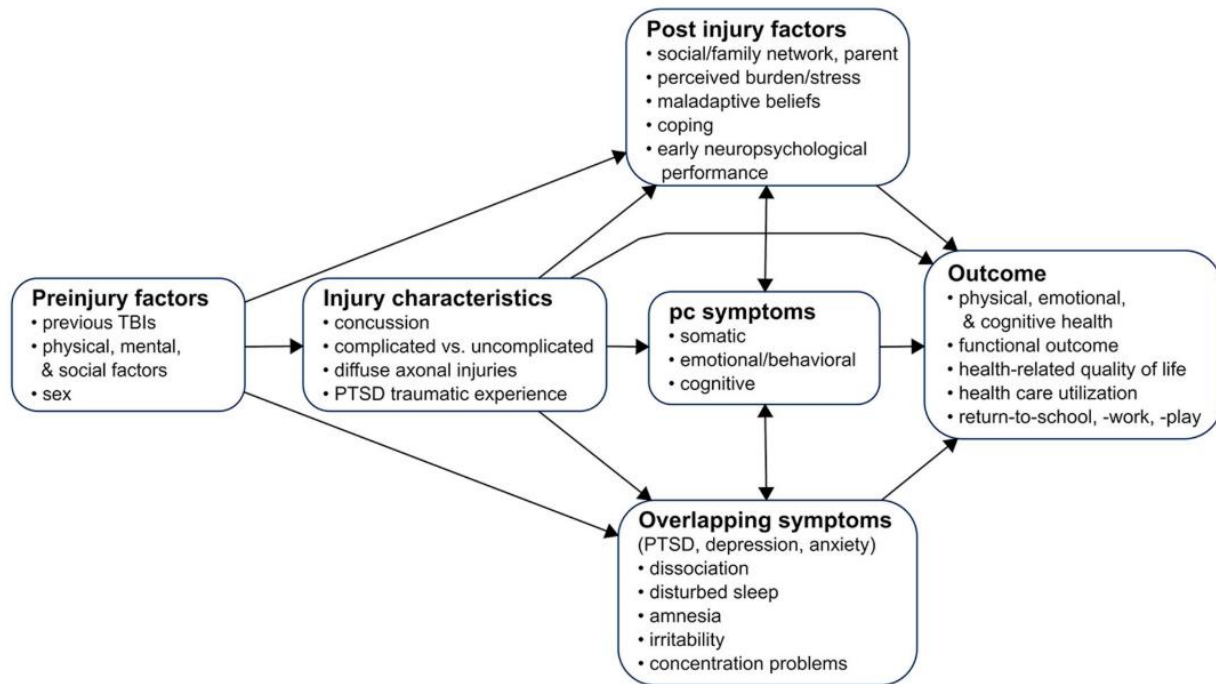

Figure 1

A model of post-concussion symptoms after mild TBI created by Polinder et al., (2018) adapted from Yeates (2010).

This model adapted by Polinder et al. (2018) was used as a guide to create the proposed multidimensional framework that guided the present thesis work (see Figure 2). Additional aspects were also drawn from a model by Mollayeva et al. (2018), where the constructs of sex and gender were importantly noted to be inextricably linked to factors influencing one's health status trajectory. Therefore, sex was included as a potential moderating effect that had been

included in the framework when examining potential differences in chronic pain outcomes. Gender identity was not asked in this sample; however, gender would be treated in the same way as sex and deserves attention and inclusion for future research. Additionally, given the sample population and the literature reviewed above, serving status (i.e., veterans vs. active-duty) was included as a potential moderating influence on the outcome (i.e., chronic pain conditions).

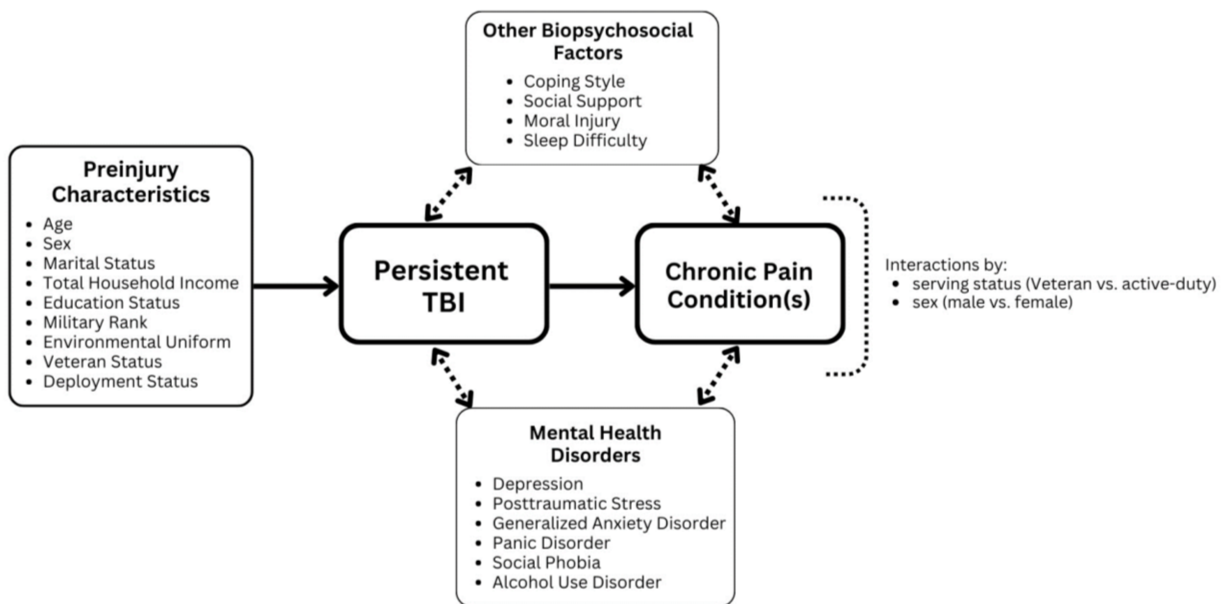

Figure 2

The proposed framework of the biopsychosocial relationship between persistent TBI and chronic pain condition(s) to guide this thesis. Framework was influenced by Polinder, et al. (2018), and Mollayeva et al. (2018)

Figure 2 presents the framework that was used to guide this thesis, based on this study's dataset (i.e., sample, variables). The framework for this study demonstrates the proposed trajectory from persistent TBI to the development of one or more chronic pain conditions. As mentioned, chronic pain outcomes considered sex (male vs. female) and serving status (veteran vs active-duty) as potential moderating influences of the chronic pain outcomes associated with TBI.

Within the model were three main overarching categories that were hypothesized to

influence the relationship between TBI and chronic pain conditions (i.e., preinjury characteristics, mental health disorders, and psychosocial factors). These overarching categories demonstrated the importance of the biopsychosocial model, in that there is individual variance within each section of the model that should be considered to understand an individual's pathway and outcome more accurately. The preinjury characteristics considered differences in a person's demographic and military characteristics; identifying characteristics of the individual before and/or during the injury. The mental health disorders category facilitated the examination of mental health disorders that may be associated with this relationship. Lastly, other biopsychosocial factors considered influences at the individual's biological, social, and psychological level (e.g., how they cope, levels of social support, sleep problems) and how these may be associated with co-occurring persistent TBI and chronic pain conditions. Each of these categories and steps are described in further detail below.

Preinjury Characteristics

Preinjury characteristics include both sociodemographic and military identifiers of the individual that have been demonstrated to be associated with persistent TBI and/or chronic pain in past literature.

Sociodemographic Characteristics

Within the general population, sociodemographic characteristics shown to be associated with persistent TBI symptoms included female sex and having a lower education status (Mollayeva et al., 2017; Polinder et al., 2018). Similarly, older age, female sex, lower education, and less perceived income have been significant risk factors shown to be associated with the development of chronic pain conditions (Prior et al., 2017). Important to note, is that the prevalence of TBIs, in general, have commonly been associated with male sex (Davies et al., 2023); however, female sex has been demonstrated to be a significant risk factor for experiencing long-term symptoms of TBI, including chronic pain post-TBI (Grandhi et al., 2017). In a recent review on sex and gender differences within TBI outcomes, the authors similarly noted a difference by sex, such that long-term TBI outcomes initially were more prevalent among females; however, this difference did not remain significant after three months (Mollayeva et al., 2018). Within the general population, differing patterns of chronic pain

outcomes following TBI for males and females have also been shown; females have experienced higher levels of headaches, while males have more commonly experienced lower back pain (Grandhi et al., 2017; Khoury & Benavides, 2018). Similarly, sex differences have been observed among those with chronic pain, where females have been shown to be more likely to experience gastrointestinal conditions and arthritis in comparison to males in the general population (Mills et al., 2019). While gastrointestinal dysfunction has been associated with TBI in past literature, little is known about the prevalence of gastrointestinal conditions among those with persistent TBI (Hanscom et al., 2021).

Similar to the general population, being male and of a younger age have been associated with TBI within the Canadian military (Garber et al., 2014). Among active-duty CAF members with chronic pain, those who were male, had an unpartnered marital status, and lower education status were more likely to experience chronic pain conditions (Perera et al., 2021). Similarly, Canadian veterans who were male and had lower levels of education were more likely to experience chronic pain (Perera et al., 2021; VanDenKerkhof et al., 2015). In one American veteran study there was a higher prevalence of chronic pain among females, while another American veteran sample showed the opposite (Otis et al., 2011; VanDenKerkhof et al., 2015). Again, similar to the general population, female veterans have been shown to be more likely to experience chronic headaches after TBI, while male veterans were more likely to experience chronic back pain (Kim et al., 2018).

Military Characteristics

Within the military context, there are some factors that have been shown to be associated with the experience of TBI and chronic pain. In American studies, service members (SMs) who actively served in OEF/OIF (i.e., deployed), served in the Army uniform, and were younger and male were more likely to experience co-occurring TBI and chronic pain (Bosco et al., 2013; Song et al., 2020). In Canadian military studies, there have been no published demographic or military characteristics associated with co-occurring TBI and chronic pain. However, among CAF personnel, junior non-commissioned status and serving in the Regular Force (vs. Reservists) has been associated with TBI (Garber et al., 2014). In a study examining chronic pain among CAF SMs and veterans, veterans were shown to be two times more likely to experience

chronic pain conditions in comparison to SMs, even after adjusting for sociodemographic variables (Perera et al., 2021). Additionally, military personnel who served in the land environment and in junior non-commissioned status had a higher prevalence of chronic pain (Perera et al., 2021; VanDenKerkhof et al., 2015).

Moderating Influences on TBI and Chronic Pain Conditions

Understanding sex and gender trends and influences is a growing focus in the current literature. In general, it has been difficult to reliably and accurately study sex and gender differences in research involving military populations, a profession historically dominated by males (Kim et al., 2018). As described earlier, male sex has consistently been associated with a higher incidence of TBI in comparison to female sex; however, there remains inconsistency in the literature surrounding sex differences among those with persistent TBI. In one past study of U.S. military members who experienced TBI, gender was analysed as a potential moderator among those with pain; however, there were no significant effects found (Hoot et al., 2018).

The current literature on chronic pain conditions have similarly demonstrated that differences are present between veteran and active-duty military personnel. However, chronic pain differences have been under-examined among those with persistent TBI. Among U.S. military personnel with TBI, there have been limited chronic pain findings that examine differences between veterans and active-duty members, consider chronic pain conditions, or have included examining more than one condition (Blakey et al., 2018; Bosco et al., 2013; Hoot et al., 2018; Nampiaparampil, 2008; Seal et al., 2017). To date, no studies have examined or compared the occurrence of persistent TBI among CAF SMs and veterans. Past evidence has indicated persistence of TBI symptoms to be a contributing factor in no longer meeting fitness for duty, suggesting among CAF personnel with persistent TBI, a higher proportion may be veterans (Garber et al., 2014). It is important to understand whether there are distinct differences in chronic pain conditions between active-duty soldiers and veterans to better understand their comorbidities and overall symptom burden.

To date, there have been no studies examining differences in chronic pain conditions by sex (i.e., male, female) or serving status (i.e., veteran, active-duty) among CAF members with persistent TBI. To help address these gaps in the literature, sex (males vs. females) and serving status (veteran vs. active-duty) were examined as moderators of the relationship between

persistent TBI and each individual chronic pain condition.

Mental Health Disorders

One of the most common comorbidities observed among those experiencing co-occurring TBI and chronic pain is a mental health disorder. While mental health disorders may originate before the TBI injury and thereby act to exacerbate the persistence and morbidity of symptoms, TBI has also been shown to be the direct cause of novel negative mental health symptoms and comorbid disorders (Davies et al., 2023; Howlett et al., 2022).

In a recent global literature review, individuals with mild TBI had an estimated 15-52% likelihood of experiencing co-occurring depressive symptoms and approximately 70% reported anxiety symptoms (Faulkner et al., 2020). Other TBI reviews have described similar results, with significantly higher prevalence of affective disorders (i.e., anxiety and depression) among those with mild or largely mild TBI, in addition to higher odds of developing other mental health disorders, including panic disorder and social phobia (Howlett et al., 2022). PTSD is one of the most frequently observed mental health disorders found to co-occur with TBI, which is suggested to be due to the nature of the traumatic injury event itself and the impact of axonal injury (Howlett et al., 2022). Among individuals with any TBI severity (i.e., mild, moderate or severe), PTSD has demonstrated a pooled prevalence of 13.8% (Polinder et al., 2018) within the general population.

The prevalence of PTSD and other mental health disorders among those with TBI drastically increases among military personnel. In a cross-sectional study on American veterans, those with TBI demonstrate higher prevalence of depression (43% vs. 25%) and PTSD (31% vs. 11%) in comparison to those without TBI (Hoot et al., 2018). Among American veterans with TBI and chronic pain, the co-occurrence of depression and PTSD have been shown to have no interactions on this relationship, but their presence has suggested additive effects, where those with TBI and co-occurring depression or PTSD had a stronger association with chronic pain in comparison to those with TBI alone or any mental health disorder alone (Seal et al., 2017). To date, there have been no studies that have examined the prevalence of mental health disorders among CAF active-duty members and veterans with persistent TBI and chronic pain conditions. Further, no CAF studies have examined if co-occurring mental health disorders act as moderators between persistent TBI and chronic pain conditions. However, chronic pain research on

Canadian military populations has shown that veterans with a mental health disorder (i.e., depression, generalized anxiety disorder (GAD), PTSD, social phobia, or panic disorder) had significantly increased odds of reporting chronic pain conditions (Perera et al., 2021). Similar findings were shown for active serving members, but only among those with depression, GAD, and panic disorder (Perera et al., 2021). Moreover, findings on Canadian veterans showed that among those with at least one mental health condition, 85% experienced co-morbid chronic pain (vs. 58% without any mental health disorder) (VanDenKerkhof et al., 2015).

Substance abuse, including alcohol abuse, has been associated with TBI, and with chronic pain; increased alcohol use associated with chronic pain has been suggested to be a form of pain relief that can lead to dependency or abuse (Brenner et al., 2023; Mills et al., 2019). In a recent American cohort study of soldiers with a history of TBI, there was a significantly elevated prevalence of alcohol use disorders (AUD) in comparison to those without TBI (31.9% vs. 10.3%, respectively) (Brenner et al., 2023). However, this association is not well understood among those with persistent TBI, and little is known about the relationship AUD may have with co-occurring persistent TBI and chronic pain conditions.

In sum, while those with TBI and/or chronic pain conditions have been shown to have greater prevalence of mental health disorders, there have been no studies to date that have examined whether differences exist in mental health disorders diagnoses when comparing those with persistent TBI and chronic pain conditions in comparison to those with persistent TBI without chronic pain.

Psychosocial Factors

Coping Style

The style in which individuals cope with stress and difficult situations in their daily lives has been shown to be associated with TBI outcomes and persistence of symptoms (Faulkner et al., 2020; Polinder et al., 2018; Scheenen et al., 2017). Coping styles often fall into categories, for example: 1) adaptive coping (e.g., problem-focused coping) where the focus is on identifying the problem or stressor and then proactively working towards alleviating said problem or stressor, and 2) maladaptive coping (e.g., avoidant or self-medication coping) where the individual actively avoids facing or dealing with the problem or stressor, including thoughts of

wishing the situation away or responding with drug use (Gregório et al., 2014; Romero et al., 2020). Use of adaptive coping strategies (i.e., problem-focused coping) has been described as a potential method for preventing chronic TBI (Khoury & Benavides, 2018); whereas use of avoidant coping strategies have been shown to be associated with higher reports of chronic pain and pain severity in those with TBI, even after adjusting for comorbid PTSD (Nampiaparampil, 2008).

There are potential associations between premorbid coping styles and outcomes of TBI, wherein those with maladaptive coping strategies (i.e., avoidant coping) showed poorer outcomes in emotional functioning and perceived quality of life post-TBI (Faulkner et al., 2020). Coping styles have also been shown to change after injury, wherein individuals post-TBI showed decreased use of problem-focused coping and an increased or steady use of avoidant or emotional-focused (e.g., self-blame, worry) coping strategies (Haller, 2017; Scheenen et al., 2017). These findings, although mixed, suggest that how one copes with their emotions and daily stressors can have a significant impact on their outcomes post-TBI. Within the context of chronic pain, poor coping skills (i.e., avoidant or self-medication coping strategies) have been associated with both the development of chronic pain and an increased disability from pain (Cohen et al., 2021; Mills et al., 2019). A better understanding of the role of coping on the relationship between persistent TBI and chronic pain is warranted and may help identify routes of prevention or therapeutic intervention.

Moral Injury

Moral injury (MI) has been described as a construct associated with, but ultimately unique from, PTSD and is defined as the culmination of events that have betrayed or transgressed one’s moral beliefs (Griffin et al., 2019; Litz et al., 2009). Moral injury can include one’s own acts, as well as failing to prevent or witnessing another’s immoral acts (Griffin et al., 2019; Ranney et al., 2022). This is a growing area of research that is especially relevant to research involving military populations, as military members are subject to increased risk of experiencing potentially morally injurious events due to their line of work (Hinkel et al., 2022; Litz et al., 2009). Past studies on American veterans examining MI have demonstrated an association between MI betrayals or MI acts related to the self and chronic pain outcomes, including increased pain and arthritis (Griffin et al., 2019; Hinkel et al., 2022; Ranney et al.,

2022). Despite MI being a growing field, there is a dearth of literature examining the relationship between MI and TBI, including co-occurrence of outcomes like the development or maintenance of chronic pain. Interestingly, in a review of TBI and suicidality, the authors noted increased activity in the frontal lobes after TBI, specifically acknowledging increased prefrontal cortex (PFC) activity, which has been described as a brain area related to negative moral feelings (Wadhawan et al., 2019). Therefore, it is possible that increased PFC activity post-TBI, especially among military personnel who are exposed to morally injurious events, could result in greater severity of MI, which could in turn perpetuate adverse outcomes including increased pain. In regard to chronic pain, a recent U.S. veteran study described MI as being significantly linked to reports of chronic pain, while also accounting for comorbid mental disorders (i.e., depression and PTSD) (Hinkel et al., 2022). Research that examines the relationship MI has on co-occurring persistent TBI and chronic pain conditions is needed to address potential implications and could be relevant for improving assessment and treatment of military personnel exposed to moral injuries and traumatic brain events.

Social Support

The presence of strong social support in one's life has been shown to be associated with an improved recovery post-TBI (Faulkner et al., 2020; Pugh et al., 2018). Moreover, a recent review of post-concussion symptoms in mild TBI cases suggested that increased social support and community integration may lower the risk of the development and/or maintenance of chronic effects of TBI (Polinder et al., 2018). Similar to this, a retrospective cohort study of American veterans, demonstrated that those with TBI, in comparison to those without had increased difficulty with community integration, family functioning, and had lower levels of social support, suggesting lowered social support may be associated with worsened or prolonged TBI symptoms (Pugh et al., 2018). The reduction in one's social support, including worsened satisfaction with overall social support, has also been associated with poorer health and quality of life after TBI (Tomberg et al., 2007). The reduction in seeking or engaging with social supports post-TBI may be related to changes in brain structures after injury, including structures related to executive functioning and memory (Bhattrai et al., 2019; Spitz et al., 2013). Social support shows a similar influence on chronic pain outcomes, in which poor social support and

social withdrawal have been associated with an increased occurrence of chronic pain (Cohen et al., 2021). Furthermore, social support has been hypothesized to act as a buffer to negative physical and emotional health outcomes and has been shown to be associated with improved pain outcomes among those with chronic pain (e.g., lowered pain and reduced burden) (Meints & Edwards, 2018). However, to date, there has been no investigation into the influence of social support on the relationship between persistent TBI and chronic pain conditions, including the examination into the potential of the level of social support moderating this relationship.

Sleep Difficulties

Impaired sleep (i.e., increased daytime sleepiness, fatigue, insomnia) has been strongly associated with both TBI and chronic pain, occurring together and on their own (Herrero Babiloni, Baril, et al., 2023; Hoot et al., 2018; Lavigne et al., 2015; Mumbower et al., 2019). Sleep difficulties after TBI can occur over long-periods of time post-injury and have been described as a major contributor to the development of further difficulties, including chronic pain and mental health disorders (Herrero Babiloni, Baril, et al., 2023; Martin et al., 2023; Mollayeva et al., 2015). Long-term epidemiological research has demonstrated that, among individuals with persistent TBI, chronic pain and sleep disorders are the most common comorbidities experienced 2 and even 5 years after injury (Martin et al., 2023). In a U.S. cross-sectional study with SMs and veterans, sleep difficulties were shown to have a significant mediating relationship on TBI and pain interference and TBI and pain intensity (Hoot et al., 2018). Sleep impairments have also been described as an outcome of TBI; when left untreated, sleep disorders in combination with TBI, have been suggested to be a potential route or contributor to pain outcomes (Martin et al., 2023). While the occurrence of sleep difficulties appears to be common after TBI, or alongside those suffering from chronic pain, the relationship among both is still unclear. Sleep impairments may be due to the injury itself, because of neural or structural damages; from changes in the individual's lifestyle post-injury; caused by the complex comorbidities of chronic pain and psychological disorders post-TBI, or a combination of all of the above (Grandhi et al., 2017; Herrero Babiloni, Baril, et al., 2023). Adding to the gaps in current literature, there have been no studies examining the relationship between sleep difficulties and persistent TBI with chronic pain conditions among CAF active serving members and veterans, including understanding if

sleep problems act as moderator on this relationship.

Study Objectives

The aim of the current study is to examine, in detail, the relationship between persistent TBI (i.e., symptoms lasting for 6 months or longer) and chronic pain conditions (i.e., arthritis, back problems, gastrointestinal conditions, and migraine headaches) in a Canadian military sample, including potential preinjury characteristics (i.e., sociodemographic and military demographics), mental health disorders (e.g., depression, PTSD) and other biopsychosocial factors (i.e., social support, sleep difficulty), as well as potential moderators (i.e., sex and serving status) that impact this relationship. This study is a secondary data analysis of the Canadian Armed Forces Members and Veterans Mental Health Follow-up Survey (CAFMVHS) collected in 2018. This large cohort study dataset allows for the novel examination of the relationship between persistent TBI and chronic pain conditions among a CAF population including serving members and veterans.

Quantitative Research Questions and Hypotheses

Research questions and supporting hypotheses this thesis study examined include:

1. Are CAF members with persistent TBI more likely to experience chronic pain conditions (i.e., arthritis, back problems, migraine headaches, and gastrointestinal conditions) in comparison to those without persistent TBI?
    a. Does sex (i.e., male vs female) moderate the relationship between persistent TBI and chronic pain conditions (i.e., arthritis, back problems, migraine headaches, and gastrointestinal conditions)?
    b. Does serving status (i.e., active serving vs veteran) moderate the relationship between persistent TBI and chronic pain conditions (i.e., arthritis, back problems, migraine headaches, and gastrointestinal conditions)?

It is hypothesized that CAF members with persistent TBI will be more likely to experience arthritis, back problems, and migraine headaches in comparison to those without persistent TBI.

a) *Sex is hypothesized to moderate the association between persistent TBI and chronic pain conditions, such that female sex, compared to male sex, will demonstrate a stronger relationship between persistent TBI and migraine headaches, while male sex, compared to female sex, will demonstrate a stronger relationship between persistent TBI and back pain.*

b) *Serving status is hypothesized to moderate the association between persistent TBI and chronic pain conditions, such that veteran status will demonstrate a stronger relationship between persistent TBI and all chronic pain conditions in comparison to active-duty status.*

2. What preinjury characteristics (i.e., sociodemographic, and military demographics) predict the co-occurrence of persistent TBI and chronic pain conditions among CAF members, compared to persistent TBI alone?

It is hypothesized that younger age, unpartnered marital status, lower education, junior non-commissioned rank, serving in the land environment, veteran status, and a history of deployment will be more likely among those experiencing co-occurring persistent TBI and chronic pain conditions in comparison to those with persistent TBI and no chronic pain conditions.

3. Are CAF members with co-occurring persistent TBI and chronic pain more likely than those with TBI alone to experience mental health disorders (e.g., depression, PTSD, etc.)?

    a. Does the presence of a mental health disorder moderate the association between persistent TBI and chronic pain conditions?

It is hypothesized that depression, PTSD, and AUD will be more likely among those experiencing co-occurring persistent TBI and chronic pain conditions in comparison to those with persistent TBI and no chronic pain conditions.

a) Depression, PTSD, and AUD are hypothesized to moderate the association between persistent TBI and chronic pain conditions, such that these mental health disorders will demonstrate a significant interaction between persistent TBI and chronic pain conditions.

4. Are CAF members with co-occurring persistent TBI and chronic pain more likely than those with persistent TBI alone to endorse certain biopsychosocial factors (e.g., problem-solving coping, avoidant coping, etc.)?
    a. Do certain biopsychosocial factors moderate the association between persistent TBI and chronic pain conditions?

It is hypothesized that a lower use of problem-solving coping; higher use of avoidant and self-medication coping styles, lower social support, higher levels of moral injury, and increased sleep difficulty will be more likely among those experiencing persistent TBI and chronic pain conditions in comparison to those with persistent TBI and no chronic pain conditions.

a) Problem-solving, avoidant and self-medication coping styles, lower social support, and sleep difficulty are hypothesized to moderate the association between persistent TBI and chronic pain conditions, such that they will demonstrate a significant interaction between persistent TBI and chronic pain conditions.

Chapter 2: Methods

Design of the Canadian Armed Forces Members and Veterans Mental Health Follow-up Survey (CAFVMHS)

Sample

The CAFVMHS is a nationally representative follow-up study of Regular Force members and veterans who originally participated in the nationally representative Canadian Community Health Survey on Mental Health and Wellbeing: Canadian Forces Supplement (CCHS-CFS) conducted in 2002 (Statistics Canada, 2004, 2018b). The CAFVMHS sample consisted of 2,941 respondents out of the original 5,155 CAF active-duty members aged 15-64 years old who completed the CCHS-CFS in 2002 (response rate of 68%) (Afifi et al., 2021). The 2018 CAFMHS also included CAF members who released from service between 2002 and 2018 (66% veterans, 34% active-duty) (Afifi et al., 2021). The CAFVMHS data were collected from January to May in 2018 by Statistics Canada. All respondents were interviewed by Statistics Canada trained lay interviewers using computer-assisted personal interviews (CAPI) (Statistics Canada, 2019). The survey itself took approximately 75 minutes to complete and was often completed in the respondent's home (Statistics Canada, 2019). The survey was designed collaboratively with the expertise of a group of mental health professionals, members of Statistics Canada, international researchers, policymakers and stakeholders. Additional information on the survey methodology used in the CAFVMHS can be found on the Statistics Canada website and in a published study by Afifi and colleagues (Afifi et al., 2021). Statistics Canada created longitudinal weights to be used for the CAFVMHS data in order to make the sample representative of the 2002 CAF Regular Force (Statistics Canada, 2019).

Subsample of Interest

A subsample of participants will be selected to be included in this study for research questions 2-4. We will use two questions to identify participants of interest, namely "Do you have (chronic pain condition variable)?" and "Do you have effects of a traumatic brain injury (TBI) or concussion?". To answer yes to either question, the effects of the chronic pain condition/TBI, had to be considered a "long-term condition" meaning it was expected to last or already have lasted for 6 months or longer and have been diagnosed by a health professional. The respondents who answered yes to experiencing effects of TBI will be the first sub-sample

examined and will be used to determine the prevalence of chronic pain conditions experienced among these individuals. Secondly, those who answer yes to TBI and any of the following: arthritis, back problems, intestinal/stomach ulcers, irritable bowel syndrome, irritable bowel disease, and migraines/headaches will be used to create the second sub-sample of TBI + Chronic Pain Conditions which will be used for the remaining research questions.

Measures

Persistent Traumatic Brain Injury

Respondents self-reported the experience of long-term TBI, which was assessed by a single item. Specifically, long-term effects of a TBI were assessed by asking if the respondent was "currently dealing with the effects from a traumatic brain injury or concussion" (Statistics Canada, 2018a). For the respondent to answer 'Yes', the TBI had to be considered a "long-term condition" meaning it was expected to last or had lasted 6 months or longer and was diagnosed by a health professional. In this study, individuals who endorsed long-term effects of TBI were coded as 1, whereas an individual with no persistent TBI was coded as 0.

Chronic Pain Conditions

Physical health conditions were measured using Statistics Canada's chronic conditions module. The authors define chronic pain conditions as self-reported physical conditions that met the following criteria: a) the condition was considered to be long-term, meaning "expected to last or already have lasted 6 months or longer", b) had been diagnosed by a health professional, and c) is known to be strongly correlated with endorsement of chronic pain in past research in CAF populations and according to the International Classification of Diseases and Related Health Problems (ICD) of the World Health Organization (Perera et al., 2021; Statistics Canada, 2018a; World Health Organization, 2019). The chronic pain conditions assessed in this study included arthritis, back problems, migraine headaches, and gastrointestinal conditions (irritable bowel syndrome [IBS]; inflammatory bowel diseases [IBD]; Crohn's disease and ulcerative colitis; and intestinal and stomach ulcers). Initially, each chronic pain condition was assessed individually; in subsequent analyses a combined variable of 'any chronic pain condition' was created based on a) respondents endorsing any one of the chronic pain conditions, b) the chronic pain condition had a statistically significant association with persistent TBI.

Sociodemographic Characteristics

Sociodemographic variables examined include sex (male, female; nominal variable), age (continuous variable), marital status (single, married/common-law, separated/divorced/widowed; nominal variable), past-year total household income (less than $50,000, $50,000-$99,999, $100,000 or more; ratio variable), and highest level of educational attainment (less than high school diploma, high school diploma, some post-secondary, bachelor's degree, above bachelor's degree; ordinal variable).

Military Characteristics

Military characteristics examined included current/last served in military ranking (junior non-commissioned, senior non-commissioned, officer grouping; ordinal variable), serving status (veteran, active-duty; nominal variable), current/last served environmental uniform/military branch (air, land, sea; nominal variable), and lifetime deployment status (never deployed, deployed at least once; nominal variable).

Mental Health Disorders

Mental health disorders were assessed and classified using the valid and reliable World Health Organization Composite International Diagnostic Interview (WHO-CIDI) (Robins, 1988). The WHO-CIDI is a fully-structured diagnostic interview that was used in this survey to assess mental health disorders according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (5th edition; DSM-5) criteria, conducted by trained lay interviewers (American Psychiatric Association, 2013; Sareen et al., 2021; World Health Organization, 1993). Mental health disorders were assessed in a past-year timeframe, which aligns with the current effects reported of TBI and chronic pain condition. These included major depressive episodes (MDE), posttraumatic stress disorder (PTSD), generalized anxiety disorder (GAD), panic disorder (PD) and social phobia (SP). For this study, these items will be treated as dichotomous nominal variables, with a 'yes' or 'no' answer. Past-year alcohol abuse and dependence was also assessed based on the WHO-CIDI, according to DSM-IV criteria. A derived dichotomous (yes/no) variable for AUD was created based on respondents who endorsed past 12-month alcohol dependence or alcohol abuse; this criteria has been established in previous literature (Taillieu et al., 2020). Each mental health disorder was first assessed individually; a combined variable of

'any mental health disorder' was created based on respondents endorsing any one of the above-mentioned disorders.

Coping with Stress

Respondents were asked about their frequency of use of 14 different coping strategies when dealing with stress. These items were derived from the Ways of Coping Questionnaire, the Coping Inventory to Problems Experienced (COPE) scale, and the Coping Strategy Indicator (Statistics Canada, 2003). For example, respondents were asked 'When dealing with stress do you: talk to others, avoid people, smoke or drink, or use exercise' (Statistics Canada, 2018a). For each item, responses were rated on a 4-point ordinal scale, ranging from often (1) to never (4). Using factor analysis, these items had been defined and grouped into three specific styles of coping: problem-focused (4 items, total score ranging from 4-16; e.g., how often do you try and solve the problem), avoidant (5 items, total score ranging from 5-20; e.g., avoid being with people), and self-medication (3 items, total score ranging from 3-13; e.g., feel better by using drugs or medication) (Mota et al., 2013). Previous CAFVMHS studies have used and established the predictive validity of these three coping variables (Enns et al., 2021; Mota et al., 2021). For the purposes of this study, each coping variable was dichotomized at the sample median into those who endorsed 'low use' (i.e., < or = median) and those who endorsed 'high use' (i.e., > median) of each coping style.

Social Support

Social support was assessed using the Medical Outcomes Study (MOS) Social Support Survey in 2018 (Sherbourne & Stewart, 1991). This measure has a total of 19 items that use a 5-point scale (1-5) ranging from 1 'none of the time' to 5 'all of the time'. Items assessed the respondent's level of affectional, emotional, and informational support received in the past year, as well as their level of active social interaction in the past year. An example of an item asked included, 'In the past 12 months, did you receive the following support: …someone who listens to you/gives you advice/gives you information/you can confide in/advises you/to share your worries and/or fears with/to offer helpful suggestions/to understand your problems?' (Statistics Canada, 2018a). The 19 items were summed to create a single continuous variable, with a range of 0-76, where higher scores equated to higher levels of social support (Mota et al., 2021). For the purposes of this study, the continuous variable was dichotomized at the sample median into

those who endorsed ‘low social support’ (i.e., < or = median) and those who endorsed ‘high social support’ (i.e., > median).

Moral Injury

Moral injury was self-reported using the Moral Injury Events Scale (MIES), which includes 9 different items that ask respondents whether or not they’ve ever experienced a variety of moral injury-related events (Nash et al., 2013). Psychometric assessment of the scale grouped moral injury events into 3 overarching categories: perceived transgressions by others (i.e., events where the respondent witnessed immoral acts done by others), perceived transgressions to self (i.e., events where the respondent violated or acted against their own moral code or was troubled by their failure to act), and perceived betrayals (i.e., events where the respondent felt personally betrayed by their trusted leaders, fellow military SMs, or someone outside of the military) (Plouffe et al., 2023). Individual items were scored on an interval 6-point scale, ranging from 1 = strongly agree to 6 = strongly disagree. A continuous score was created from all 9 items, with totals ranging from 9-54. Higher scores indicated greater moral injury severity. Of importance, Statistics Canada implemented conditional logic skipping when respondents completed the MIES, in which if a respondent selected “strongly disagree” for specific statements, they automatically had the “strongly disagree” response applied to a subsequent item (e.g., “strongly disagree” selected for item “I saw things that were morally wrong” then automatically applied to the following item “I am troubled by having witnessed others’ immoral acts”) (Statistics Canada, 2018a). Past research has examined the potential impact of the use of logic skipping and found that when compared to samples where MIES did not use skip logic, the outcomes between participant responses on these items differed minimally and did not pose an issue (Plouffe et al., 2023). For the purposes of this study, the moral injury continuous variable was dichotomized at the sample median into those who endorsed ‘low moral injury’ (i.e., < or = median) and those who endorsed ‘high moral injury’ (i.e., > median).

Sleep Difficulty

Respondents were asked items that pertained to their overall general health, including items about their sleep quality. To examine sleep difficulty, respondents were asked “How often do you have trouble going to sleep or staying asleep?” (Statistics Canada, 2018a). This categorical variable used a 5-point scale, ranging from ‘none of the time’ (1) to ‘all of the time’

(5). For the purposes of this study, the sleep difficulty variable was dichotomized at the sample median into those who endorsed ‘low sleep difficulty (i.e., < or = median) and those who endorsed ‘high sleep difficulty’ (i.e., > median).

Statistical Analyses

All analyses were conducted using STATA Version 16 (StataCorp, 2019). Sampling weights calculated and created by Statistics Canada were applied to all analyses to account for attrition between datasets and to ensure representativeness to the CAF target sample, originally collected in 2002. Bootstrapping weights were employed and used as a standard error estimation technique to account for the complex stratified sampling design of the survey.

Logistic regression analyses were used to examine the relationship between independent variables and the outcome (chronic pain condition). This test is well-suited for describing the relationship between variables in this study and is appropriate for the number of variables being examined due to the dichotomous nature of the dependent variables (i.e., TBI and chronic pain conditions) and the large sample size. There are five critical assumptions that have been suggested to be verified as best practice before using logistic regression modeling and these include: 1) the outcome variable(s) must be dichotomous, 2) all observations (i.e., responses) must be independent of one another, 3) there must be a linear relationship for continuous independent variables (e.g., age) and their transformed logit-outcomes, 4) the absence of or minimal multicollinearity among independent variables in the same model, and 5) the absence of highly influential outliers (Pal, 2021; Peng et al., 2002; Stoltzfus, 2011). Before study analyses were completed, all assumptions were verified using statistical evaluations. The first assumption was met upon verifying the dependent variables, the presence of one of or any chronic pain condition (i.e., arthritis, back problems, gastrointestinal conditions, or migraine headache), were dichotomous (i.e., yes, or no) variables. The second assumption was met through self-checking that there were no duplicate or matched responses present within this dataset. To verify assumption three, interactions were tested between continuous independent variables and their respective logarithm to ensure there were no significant interactions found. Results showed some variables had non-linear relationships; therefore, dummy codes were created to make dichotomized variables using a median-split as has been recommended (Stoltzfus, 2011). The fourth assumption was verified by ensuring there were no strong correlations among independent

variables in analyses that incorporated the use of models with more than one independent variable. For this study, no independent variables needed to be removed and models that included more than one independent variable were conservative. Finally, the presence of few highly influential outliers was confirmed by examining the residual outputs of continuous variables; furthermore, the use of non-parametric methods (i.e., median) as discussed above, were used for continuous variables that displayed skewed data as recommended elsewhere (Pal, 2021). In sum, all assumptions of logistic regression were verified, allowing the study specific analyses to proceed.

Further to the above-mentioned assumptions, the interpretation of logistic regression models outcomes (i.e., ORs) is dependent on whether the independent variable is continuous or categorical. In this study, there were numerous continuous variables that needed to be assessed prior to completing logistic regressions to identify and determine the methods for interpretation of the findings. First, all continuous variables were examined to assess their distribution. The distribution results revealed several independent variables that were non-normally distributed. To account for the non-normally distributed continuous variables, it was decided to employ a non-parametric median split approach to apply meaningful and interpretable cut-off points to these variables and create equally representative groups (Iacobucci et al., 2015; Stoltzfus, 2011; Tustumi, 2022). The median-split dichotomized the continuous variables by first identifying the median of each original continuous variable. The median was then used to divide these variables into approximately two equally representative groupings, with the lower level representing responses at or below the median, and the higher-level representing responses above the median. While the use of employing cut-points for variables can introduce further bias and error into the study, the use of median splits for continuous variables used in regression analyses has been validated in past research (Iacobucci et al., 2015; Tustumi, 2022). The median-split variables were used for both examining descriptive cross-tabulations (i.e., prevalence) and for all logistic regression analyses. Continuous variables that were normally distributed were not split by median, instead a parametric approach using the mean was employed. This was only the case for age.

All data analyses completed for this study, including logistic regression analyses and predictive values (i.e., prevalence, mean, median), used 95% confidence intervals with bootstrapping as a measure of precision. In addition, this study used an alpha of $p < 0.05$, which

is consistent with prior research that has supported exploratory studies using unadjusted alpha levels when researchers are conservative in the number of tests completed per hypothesis in their study (Rubin, 2017). If the reader prefers a more conservative approach, the tables provided include a legend for interpreting significance which also offer $p < 0.01$ and $p < 0.001$.

Testing of Research Questions

Figure 3 provides a visual of the analysis plan for research question one. To address the first research question, the prevalence and association of persistent TBI with each comorbid chronic pain condition was examined. This was done by running descriptive cross-tabulations and logistic regressions with TBI as the independent variable and each chronic pain condition (i.e., arthritis, back problems, migraine headaches, gastrointestinal conditions, and 'any chronic pain condition;') as the dependent variable. Furthermore, for part A, moderation effects by sex (male vs. female) was examined using an interaction term for biological sex-by-persistent TBI in logistic regression analyses. Lastly, to address the hypothesis in part B, moderation effects by serving status (veteran vs. active-duty) were examined using an interaction term for serving status-by- persistent TBI in logistic regression analyses.

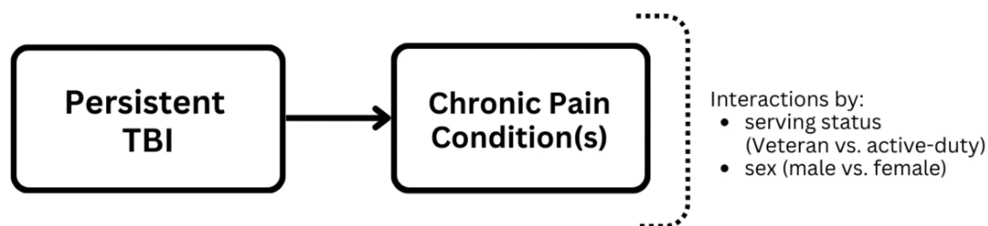

Figure 3

Analytical model for research question 1

Figure 4 provides a visual of the analysis plan for research question two. To address the second research question, the prevalence and association of each preinjury factor (i.e., sociodemographic, and military characteristics) was examined among individuals experiencing both persistent TBI and chronic pain conditions in comparison to individuals with persistent TBI alone (no chronic pain conditions). This was accomplished by running descriptive cross-tabulations and logistic regressions among a sub-group of respondents with persistent TBI,

where the dependent variable was 'any chronic pain condition', and the independent variable(s) was the preinjury factors.

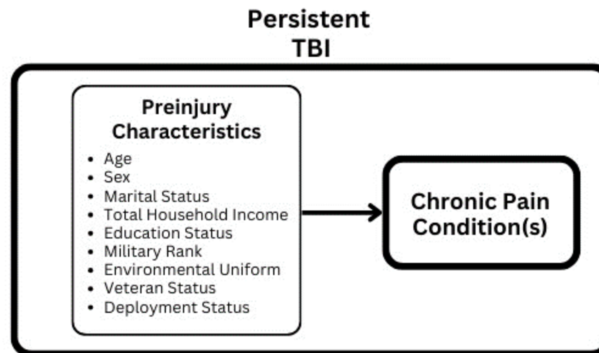

Figure 4

Analytical model for research question 2

Figure 5 provides a visual of the analysis plan for research question three. To address the third research question, the prevalence and association of mental health disorder diagnoses (e.g., depression, PTSD) were examined among individuals experiencing both persistent TBI and chronic pain conditions in comparison to individuals with persistent TBI alone (no chronic pain conditions). However, due to small cell sizes, analyses were unable to examine each mental health disorder individually. To account for the small cell sizes, all individual mental health disorders (i.e., depression PTSD, GAD, social phobia, panic disorder, AUD) were collapsed into a single 'any mental health disorder' variable. Sensitivity analyses were done to confirm the direction of the associations was the same across each individual mental health disorder and the combined 'any mental health disorder' variable. To examine the prevalence and association of any mental health disorders, descriptive cross-tabulations and logistic regressions were conducted among a sub-group of respondents with persistent TBI, where the dependent variable was 'any chronic pain condition', and the independent variable was 'any mental health disorder'. Subsequently, the logistic regressions analysis was adjusted by significant preinjury factors (i.e., serving status and military rank) to acquire an adjusted odds ratio (AOR).

To address part A of research question three, moderation effects of a mental health disorder on the relationship between persistent TBI and chronic pain conditions were examined

using an interaction term for the individual mental health disorder variables (i.e., depression PTSD, GAD, social phobia, panic disorder, AUD) and for the combined ‘any mental health disorder variable’ using logistic regression analyses. Due to the exploratory nature of the moderation analyses, any significant interactions were discussed in the results section.

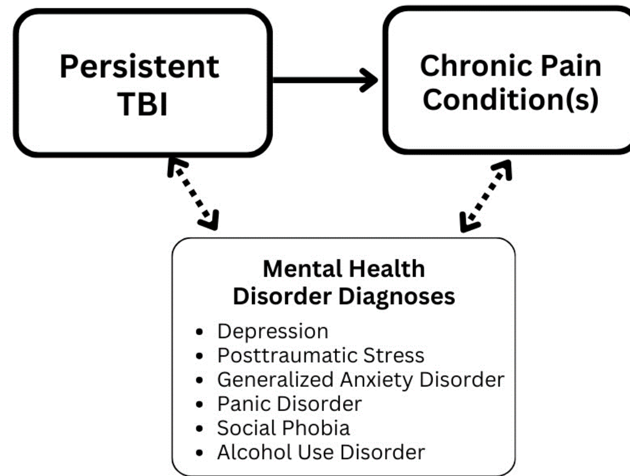

Figure 5

Analytical model for research question 3

Figure 6 provides a visual of the analysis plan for research question four. To address the fourth research question, the prevalence and association of other biopsychosocial factors (e.g., coping style, social support) were examined among individuals experiencing both persistent TBI and chronic pain conditions in comparison to individuals with persistent TBI alone (no chronic pain conditions). This was accomplished by running descriptive cross-tabulations and logistic regressions among a sub-group of respondents with persistent TBI, where the dependent variable was ‘any chronic pain condition’, and the independent variable(s) was the other biopsychosocial factors. In addition, the logistic regression analyses were subsequently adjusted by significant preinjury characteristics (i.e., sociodemographic, and military characteristics) to acquire AORs.

To address part A of research question four, moderation effects of each biopsychosocial factor on the relationship between persistent TBI and chronic pain conditions was examined

using an interaction term for each individual biopsychosocial factor-by-persistent TBI using logistic regression analyses. Due to the exploratory nature of the moderation analyses, any significant interactions were discussed in the results section.

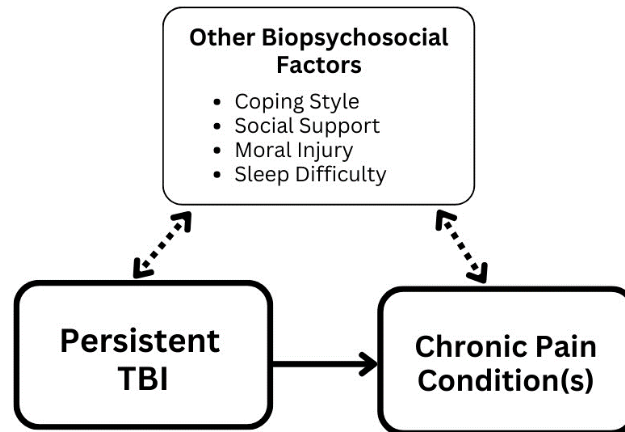

Figure 6

Analytical model for research question 4

Ethical Considerations

The CCHS-CFS and CAFVMHS datasets were voluntary surveys. Informed consent was obtained at both the 2002 and 2018 time points by Statistics Canada. All data collected for the CAFVMHS and CCHS-CFS was done in accordance with the Statistics Act (Afifi et al., 2021). The Statistics Act gives the statistics bureau, Statistics Canada, the permission and ability to collect, analyze, and publish data while always maintaining confidentiality and anonymity to the respondent(s) (R.S.C., 1985). Respondents were informed of secondary use of the data being collected by Statistics Canada and of any potential risks and/or harms of the research by Statistics Canada prior to completing consent. All data collected were subject to ethical and privacy reviews by relevant entities at Statistics Canada that serve the function of a Research Ethics Board.

The CCHS-CFS and CAFVMHS datasets were available as confidential microdata files through the Manitoba Research Data Centre. This study received access to these datasets at the

Research Data Centre after application approvals were completed. Only the author and advisors had access to the data files; no other individuals were allowed to access the datasets. Data access records were kept by the Manitoba Research Data Centre analyst, who oversaw all research activity. All working analyses and files were accessed and maintained at the Manitoba Research Data Centre on secure servers held by Statistics Canada. Final analyses, consisting of data tables and no individual respondent level data, were vetted and approved by the Manitoba Research Data Centre analyst before being released to the author. In addition to study approvals from Statistics Canada, this study received ethical approval from the Bannatyne Health Research Ethics Board at the University of Manitoba board for the purpose of this thesis.

All data accessed for this study was anonymized, ensuring privacy and confidentiality of all respondents. Data analyses and vetting protocols required a minimum of 5 individuals or more per each cell of data to safeguard the anonymity of all individuals included in the dataset. If any of the variables/data analysed resulted in cell sizes under 5 (unweighted number), these data were excluded or variables were collapsed into larger overarching variables. Additionally, any cell sizes below 10 were reviewed with the Manitoba Research Data Centre analyst to ensure all data remained anonymous.

Chapter 3: Results

Chronic Pain Conditions Among CAF Members with and without Persistent TBI

The prevalence of persistent TBI among all CAF members in this sample was approximately 6%. Table 1 demonstrates the prevalence of each chronic pain condition among individuals with persistent TBI in comparison to those without persistent TBI. The overall prevalence of any chronic pain condition among those persistent TBI was 85.7%, compared to 59.7% among those without persistent TBI. The prevalence of each specific chronic pain condition among those with and without persistent TBI was as follows: arthritis 55.2% vs. 32.2%, back problems 71.6% vs. 43.6%, migraine headaches 30.9% vs. 9.6%, gastrointestinal conditions 25.9% vs. 9.4%, respectively.

Individuals who were currently experiencing persistent TBI were significantly more likely to experience any co-morbid chronic pain condition, in comparison to those without persistent TBI (odds ratio [OR] = 4.06; 95% confidence interval [CI]: 2.42-6.80). Individuals with persistent TBI had significantly increased odds of experiencing arthritis (OR = 2.59; 95% CI: 1.84-3.65), back problems (OR = 3.27; 95% CI: 2.20-4.87), migraine headaches (OR = 4.21; 95% CI: 2.83-6.26), and gastrointestinal conditions (OR = 3.37; 95% CI: 2.23-5.09).

Moderation by Sex and Serving Status

There were no significant interactions found for sex or serving status when examining moderating effects of the relationship between persistent TBI and chronic pain conditions.

Preinjury Characteristics Among CAF Members with Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

Table 2 presents the prevalence and associations of preinjury characteristics (i.e., sociodemographic and military identifiers) for CAF members who were currently experiencing persistent TBI, with and without chronic pain condition(s). Individuals with co-occurring persistent TBI and any chronic pain condition(s) had a mean age of 49.8, 89.6% were male sex, 88.1% had a partnered marital status, 65% had a household income of $90,000 or higher, 52.5% had at least some post-secondary education, 49.7% were junior non-commissioned member ranking (39.6% senior non-commissioned members, 10.7% officer grouping), 80.5% had a

veteran serving status, 61.7% served in the land uniform (23.6% air, 14.7% sea), and 88.7% had experienced deployment(s).

Military demographics significantly associated with individuals experiencing persistent TBI and chronic pain conditions included serving status and rank. CAF members with a commissioned officer ranking (i.e., officer grouping) were at significantly lower odds than non-commissioned ranked members to have co-morbid chronic pain conditions (OR = 0.11; 95% CI: 0.23-0.53). In addition, individuals who were veterans, in comparison to those who were active-duty members, were at significantly higher odds of experiencing co-morbid chronic pain conditions (OR = 3.72; 95% CI: 1.25-11.10).

Mental Health Disorders Among CAF Members with Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

Table 3 presents the prevalence of mental health disorders among individuals who were currently experiencing persistent TBI and their association with chronic pain conditions, compared to those without chronic pain conditions. The prevalence of a mental health disorder among those with co-occurring persistent TBI and any chronic pain condition was 68.1% vs. 53.6% for those with persistent TBI and no chronic pain conditions. Although there were no significant odds to report, the findings showed a trend representing an increased likelihood among individuals with co-occurring persistent TBI and any chronic pain condition(s) to have at least one mental health disorder in comparison to individuals with persistent TBI alone (i.e., no chronic pain condition(s)). Sensitivity analyses showed trends moving in the same direction for each individual mental health disorder (i.e., depression, PTSD, GAD, social phobia, panic disorder, AUD) such that all individual mental health disorders were more likely among individuals experiencing co-occurring persistent TBI and any chronic pain condition in comparison to those with persistent TBI alone.

Moderation by Mental Health Disorders

There were no significant interactions found for any of the mental health disorders-by-persistent TBI analyses when examining the moderating effects of mental health disorders on the relationship between persistent TBI and any chronic pain condition(s).

Biopsychosocial Factors Among CAF Members with Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

Table 4 demonstrates the prevalence of other biopsychosocial factors among all individuals who were currently experiencing persistent TBI and their association with any chronic pain conditions, compared to those without any chronic pain conditions. Overall, individuals who were experiencing co-occurring persistent TBI and any chronic pain condition(s) endorsed the following: 79.1% had a low use of problem-solving coping, 59.8% had a high use of avoidant coping, and 61.3% had a low use of self-medication coping; self-assessment indicated that 59.9% had low levels of social support, 73.7% had a high level of moral injury, and 63% had high levels of sleep difficulties.

Comorbid persistent TBI and chronic pain conditions were significantly associated with problem-focused coping and sleep difficulty. More specifically, those with persistent TBI and any chronic pain conditions(s) were at decreased odds of having a high use of problem-focused coping (OR = 0.29; 95% CI: 0.10-0.80), and at an increased odds of experiencing high levels of sleep difficulty (OR = 10.67; 95% CI: 3.02-37.64), in comparison to those with persistent TBI alone.

After adjusting for significant preinjury characteristics (i.e., military rank, serving status), those with comorbid persistent TBI and any chronic pain condition(s) remained at increased odds of experiencing high levels of sleep difficulty (OR = 1.96; 95% CI: 1.32-2.90).

Moderation by Biopsychosocial Factors

One significant interaction was present when examining the moderating effect of other biopsychosocial factors on the relationship between persistent TBI and any chronic pain condition(s). Problem-solving coping-by-persistent TBI demonstrated a significant interaction on the outcome of any chronic pain condition(s) (p = 0.020). Further examination of this interaction demonstrated that individuals without persistent TBI who endorsed low problem-solving coping were not more likely to experience chronic pain outcomes; however, individuals with persistent TBI who endorsed low problem-solving coping were significantly more likely to have a comorbid chronic pain condition. Therefore, among individuals with chronic pain conditions, those who have comorbid persistent TBI experience a lower endorsement of problem-focused coping than those without persistent TBI.

Chapter 4: Discussion

This is the first Canadian study to examine, in detail, the relationship between persistent TBI and specific chronic pain conditions among military personnel and veterans. Importantly, this is also the first study to include a comprehensive look at pre-injury characteristics, mental health disorders, and other biopsychosocial factors and the potential influence they may have on this relationship. The literature base surrounding persistent TBI and chronic pain conditions, although growing, has been relatively limited with many gaps and inconsistencies present. The results from the current study contribute to the current literature base, specifically providing insight into a Canadian military population of active-duty and veteran members.

The findings from the current study demonstrated that the majority (85.7%) of individuals experiencing persistent TBI had a comorbid chronic pain condition. Looking at chronic pain conditions individually among those with persistent TBI, 71.6% had comorbid back problems, 55.2% had comorbid arthritis, 30.9% had comorbid migraine headaches, and 25.9% had comorbid gastrointestinal conditions. The present findings showed similar prevalence trends to past studies in U.S. military populations (Hinkel et al., 2022; Hoot et al., 2018; O'Neil et al., 2020). In addition, findings among those with persistent TBI highlighted certain military demographics that demonstrated increased odds of experiencing comorbid chronic pain conditions, these included junior non-commissioned military ranking and being of a veteran serving status. While the examination into mental health disorders did not display any significant findings in this study, trends suggested higher odds of experiencing any mental health disorder among those with co-occurring persistent TBI and any chronic pain condition(s) in comparison to those with persistent TBI alone. Findings regarding the other biopsychosocial factors showed significant associations among those with co-occurring persistent TBI and any chronic pain condition(s), these included problem-focused coping and sleep difficulties. A higher use of problem-solving coping was associated with lowered odds of experiencing comorbid chronic pain conditions, while a higher endorsement of sleep difficulty was associated with increased odds of comorbid chronic pain conditions. Together, these findings help to describe and elucidate the relationship between persistent TBI and chronic pain conditions among a Canadian military population.

Results by Study Hypotheses

Hypothesis 1

For the first hypothesis it was proposed that CAF members with persistent TBI would be more likely to experience arthritis, back problems, and migraine headaches in comparison to those without persistent TBI. The results from this study supported this hypothesis, with a higher prevalence and an increased odds of arthritis (55.2% vs. 32.2%), back problems (71.6% vs. 43.6%), and migraine headaches (30.9% vs. 9.6%) among CAF members with persistent TBI. Moreover, among those with persistent TBI, the odds of experiencing any chronic pain condition was over 4 times higher in comparison to those without persistent TBI (OR = 4.06; 95% CI: 2.42-6.80). These findings are in line with past studies that have demonstrated a heightened prevalence for general chronic pain and chronic pain conditions among U.S. military personnel with TBI (Hoot et al., 2018; Lee et al., 2018; Maleki et al., 2021; O'Neil et al., 2020).

Within this sample, back problems and arthritis had the highest prevalence, followed by migraine headaches. Back pain has been consistently demonstrated to be among the most common chronic pain conditions experienced by those with TBI in military samples, consistent with this study's findings (Lee et al., 2018; Uddin et al., 2019). The prevalence of arthritis within this sample, although higher, was similar to that found among a U.S. veteran sample comparing those with mild TBI to those without (43.3% vs. 28.0%, respectively) (Hoot et al., 2018). Headaches, one of the most common types of chronic pain experienced among those with TBI, have been described as exhibiting different phenotypes and trajectories post-TBI (Chen et al., 2023). The prevalence of chronic headaches, resembling migraine headaches, among U.S. OEF/OIF veterans with mild TBIs has been reported to be roughly 20%, compared to episodic headaches among approximately 78% (Maleki et al., 2021). These findings are similar to the prevalence of migraine headaches found in this sample and suggestive of a similar headache profile post-TBI. Moreover, when we examine the effects of these relationships, while back problems showed the highest prevalence among those with persistent TBI out of the four chronic pain conditions examined, migraine headaches demonstrated the strongest relationship with persistent TBI (OR = 4.21; 95% CI 2.83-6.26) followed by gastrointestinal conditions, back problems, and arthritis. These findings are consistent with past research involving U.S. veterans, where headaches and migraines demonstrated stronger associations with TBI than other chronic pain conditions (Lee et al., 2018).

Some of the heightened prevalence estimates in this study may be due to the study population being inclusive of both active-duty and veteran members, while past findings have tended to focus on one or the other. Veterans in Canada are nearly twice as likely to experience chronic pain conditions in comparison to active-duty members (Perera et al., 2021). Moreover, this study focused on individuals with persistent TBI specifically. In contrast, past findings have included TBIs with a shorter recovery period or those of a specifically mild classification, which may have different associations to comorbid chronic pain conditions.

The current literature suggests that part of the strong correlation between chronic pain and TBI seen in this and other studies can be attributed to structural and connectivity changes to the brain post-TBI (Bosco et al., 2013; Uddin et al., 2019). TBIs have been described as having two brain injury occurrences; the primary injury is associated with the TBI event itself and includes more physical damage to the skull, brain tissue, and blood flow; secondary injuries are those that result from primary injury damage and include neuroinflammation, cellular and connectivity dysregulation, and hypersensitivity (Irvine & David Clark, 2018; Lee et al., 2018). The secondary brain injuries are suggested to be significant contributors of chronic symptoms of TBI and other morbidities like chronic pain conditions (Cherup et al., 2023; Lee et al., 2018). While there is no conclusive evidence pointing to a standard mechanism linking TBI and chronic pain conditions, past research using human and animal models post-TBI have helped to elucidate mechanisms that are shown to be related. In particular, past studies have demonstrated dysfunction of pain modulation within brain pathways and alterations, including sensitization of the central nervous system post-TBI; these mechanisms have likewise been observed in chronic pain conditions like arthritis and migraines post-TBI (Bosak et al., 2022; Chen et al., 2023; Uddin et al., 2019). Future research that establishes common mechanisms could help to identify potential predictors of chronic pain conditions post-TBI and mechanisms that can be targeted for therapeutic intervention.

Findings from this study also demonstrated an increased prevalence of gastrointestinal conditions among those with persistent TBI compared to those without (25.9% vs. 9.4%), which was not included in the hypothesis. Further, a significant association was noted between persistent TBI and gastrointestinal conditions, such that persistent TBI was associated with higher odds of a gastrointestinal condition. There are currently limited studies that have examined gastrointestinal conditions among military members with any form of TBI. The higher

likelihood of gastrointestinal conditions among those with TBI reported in this study aligns with a previous study of U.S. veterans, where individuals with TBI were more likely to experience a bowel disorder in comparison to those without TBI (Lee et al., 2018). Despite a limited knowledge base among military members with TBI, gastrointestinal disruptions post-TBI have been described as a significant cause of mortality among TBI survivors (Hanscom et al., 2021). TBIs produce a stress response in the body post-injury, which includes activating the immune system. Persistent activation of the immune system and/or brain-gut axis dysfunction post-TBI have been suggested to cause widespread neuroinflammation that could lead to gastrointestinal dysfunction (Hanscom et al., 2021). Moreover, traumatic events, for example a violent TBI experienced during deployment, may influence the nervous system to be in a persistent defense response, which can cause changes in feedback loops that control the gastrointestinal tract (Kolacz & Porges, 2018).

Within the first hypothesis, it was additionally proposed that there would be moderation effects present by both sex (i.e., male, female) and serving status (i.e., active-duty, veteran) in the relationship between persistent TBI and chronic pain conditions. Sex was hypothesized to have a significant interaction with persistent TBI, such that female sex would have a higher odds of migraine headaches in comparison to male sex, while male compared to female sex would have higher odds of back pain. The results from this study did not support these hypotheses, instead no significant interactions were present for sex. Past findings among the American general population and veterans have demonstrated a heightened risk post-TBI for headaches among females compared to males. and back problems among males compared to females, suggestive of potential moderation of pain outcomes by sex (Kim et al., 2018; Meints & Edwards, 2018). However, past research examining gender as a potential moderator on pain outcomes among U.S. veterans with mild TBI similarly found no effect (Hoot et al., 2018). There were several factors that may have influenced the moderation analyses, including the overall sample size, where the number of individuals with female sex compared to male sex was strikingly disproportionate, producing a skewed ratio; limiting the ability to examine prevalence trends of chronic pain conditions by sex. Furthermore, within the military, a large proportion of the population is male, which makes it difficult to compare to findings supported by the general population where the sex ratio is more evenly distributed.

Serving status was also hypothesized to have a significant interaction with persistent TBI.

The proposed hypothesis was that among individuals with persistent TBI, veterans would have a higher odds of each individual chronic pain condition in comparison to active-duty members. The findings from this study did not support this hypothesis; there were no moderation effects present by serving status and persistent TBI for any of the chronic pain condition outcomes. Previous CAF findings have demonstrated significantly higher odds of chronic pain conditions among veterans in comparison to active-duty members (Perera et al., 2021). However, the current literature on TBI and chronic pain that is inclusive to active-duty and veteran members has been limited and not examined potential moderation on this relationship by serving status; thus, limiting existing literature to compare our findings to. Our findings may have also been influenced by the large proportion of veterans (66%) that make up the 2018 sample.

Hypothesis 2

The second hypothesis was that, among CAF members with persistent TBI, younger age, unpartnered marital status, lower education, junior non-commissioned rank, serving in the land environment, veteran status, and a history of deployment would be associated with comorbid chronic pain conditions. This hypothesis was partially proven, where individuals with junior non-commissioned rank and veteran status were significantly more likely to have a chronic pain condition comorbid with persistent TBI, compared to those with persistent TBI alone. These findings are in line with past research, given that increased risk for TBI and/or chronic pain has been demonstrated among military personnel with lower ranking and veteran status (Garber et al., 2014; Perera et al., 2021; Song et al., 2020; Uddin et al., 2019). Other sociodemographic and military characteristics hypothesized to contribute to the experience of co-occurring persistent TBI and chronic pain conditions did not provide significant results. Younger age has commonly been associated with TBIs among military personnel (Garber et al., 2014); however, chronic pain conditions have been associated with older age (Perera et al., 2021). Moreover, lasting and worsened outcomes post-TBI have been associated with older age (Dams-O'Connor et al., 2023). Therefore, the older mean age observed among those with persistent TBI and any chronic pain conditions in this study may be explained by the inclusion and high proportion of veteran members in this sample, particularly among those with persistent TBI and any chronic pain condition compared to those with persistent TBI alone; 80.5% vs. 52.6% respectively. The non-significant findings regarding deployment, uniform/environment, marital status, and educational

status may be due to the novelty of examining these factors specifically among those with persistent TBI. Prior research has shown these factors to be associated with TBI or chronic pain independently (Perera et al., 2021; Song et al., 2020; VanDenKerkhof et al., 2015); however, this study's findings suggest they may not be related to the combination of persistent TBI and chronic pain conditions, but rather related to TBI or chronic pain alone. In addition, the findings may also be due to a reduced ability to power these analyses given the relatively small sample of individuals with TBI, and the highly select military population examined (i.e., a largely older and veteran cohort). Further replication is warranted.

Hypothesis 3

For the third hypothesis it was proposed that depression, PTSD, and AUD would be more likely to be experienced by CAF members with persistent TBI and chronic pain conditions in comparison to those with persistent TBI alone. This hypothesis was not proven, in part because of limitations in the sample size, resulting in the inability to examine individual mental health disorders within this sample due to small cell sizes. Instead, all mental health disorder diagnoses were collapsed into one 'any mental health disorder' variable. The findings did demonstrate that individuals with comorbid persistent TBI and any chronic pain condition(s) did have a higher prevalence of past-year mental health disorders in comparison to those with persistent TBI alone, (68.1% vs. 53.6% respectively). Further, sensitivity analyses were completed for each individual disorder which showed prevalence estimates and ORs trending in the same direction as the 'any mental health disorder' category. A higher prevalence of mental health disorders among those with TBI and/or those with chronic pain or chronic pain conditions, has similarly been demonstrated in the literature, including military studies (Brenner et al., 2023; Cherup et al., 2023; Hoot et al., 2018; Howlett et al., 2022; Perera et al., 2021). The relationship between mental health disorders, such as depression or anxiety, and chronic pain is complex and has been described as bi-directional, where chronic pain may cause increased symptom severity, and vice versa, post-TBI (Grandhi et al., 2017; Khoury & Benavides, 2018). Similarly, alcohol abuse or dependence, which is more common among those with TBI (Brenner et al., 2023), has been suggested to be an outcome in the management of chronic pain and/or a potential consequence of the same brain dysregulation that results in chronic pain (Mills et al., 2019). In addition, mental health disorders have been suggested to play an influential role on pain development and

experiences of pain post-TBI (Hoot et al., 2018). Individuals with TBI, PTSD, and depression in particular have been shown to be at highest risk of developing chronic pain (Seal et al., 2017). Previous findings suggest there are overlapping symptoms or underlying mechanisms between post-TBI and chronic pain profiles, where mental health disorders are involved as both outcomes and drivers (Howlett et al., 2022; Khoury & Benavides, 2018). However, the exact role mental health disorders play in the co-occurrence of TBI and chronic pain conditions is still not clear. While the findings from this study present a preliminary view into this relationship, they cannot fully support the hypothesis. Future work is needed with a larger sample size to better examine how mental health disorders are associated to co-occurring persistent TBI and chronic pain conditions.

In addition, moderation effects were hypothesized, where depression, PTSD, and AUD were proposed to demonstrate significant interactions between persistent TBI and any chronic pain condition(s). The findings from this study did not support this hypothesis. Moderation was examined for each individual mental health disorder diagnosis by persistent TBI for an ‘any chronic pain condition’ outcome; no significant interactions were found. These results are in line with past work that demonstrated mental health disorders, specifically depression and PTSD, did not primarily moderate or mediate the relationship between TBI and chronic pain among U.S. veterans (Seal et al., 2017). However, due to limitations in this sample size (e.g., unstable confidence intervals), replication of these findings are warranted. Future research should examine the moderation and mediation of individual mental health disorders on the relationship between TBI and chronic pain conditions to provide a better examination and more confident results.

Hypothesis 4

The fourth hypothesis was that, among CAF members with persistent TBI, greater use of avoidant and self-medication coping, lower use of problem-solving coping, higher levels of moral injury, lower levels of social support, and increased sleep difficulty would be associated with those experiencing comorbid chronic pain conditions, in comparison to those with persistent TBI alone. This hypothesis was only partially supported. Individuals with persistent TBI and chronic pain conditions had significantly lower odds of endorsing problem-focused coping and higher odds of increased sleep difficulties, in comparison to those with TBI alone. Other

biopsychosocial factors were not found to be significantly linked to comorbid chronic pain conditions in individuals with persistent TBI. Coping strategies have an established influence on the development and maintenance of outcomes post-TBI and the development of chronic pain (Mills et al., 2019; Scheenen et al., 2017). In line with this study's findings, past literature has indicated individuals post-TBI have demonstrated a higher use of negative (i.e., avoidance, or drug use) coping strategies and a lower use of active coping, such as problem-solving strategies (Nampiaparampil, 2008; Scheenen et al., 2017; Spitz et al., 2013). Furthermore, the use of poor coping over active coping strategies, among individuals has been associated with longer disability and morbidity, including chronic pain development (Cohen et al., 2021; Mills et al., 2019). Cognitive functioning after TBI has been suggested to be a driving force for a decrease in active coping strategies (Haller, 2017; Howlett et al., 2022). Although the mechanisms underlying the use of coping strategies post-TBI are not clear, findings from this study do add to the literature, demonstrating a lowered use of problem-focused coping among those with persistent TBI, which may be involved in the development or maintenance of co-occurring chronic pain conditions. These results, in line with past findings, indicate the potential for coping strategies to be a useful target in therapeutic treatment and intervention for individuals post-TBI.

It is important to note that the association between problem-solving coping and chronic pain outcomes among those with persistent TBI was no longer found to be statistically significant after accounting for differences in serving status and military ranking. Among military personnel, avoidant coping strategies have been noted as being potentially adaptive during deployment(s), however, long-term coping strategies that are high in avoidance and low in problem-solving can lead to a reduced ability to handle life stressors (Romero et al., 2020). Therefore, one potential reason for problem-solving coping no longer being significant is that there may be significant difference in coping styles between active-duty and veteran members and/or between members of different military rankings (e.g., junior non-commissioned vs. officer grouped ranking), where one's job demands may predispose them to rely more heavily on a particular coping style.

It was also demonstrated that individuals with persistent TBI and chronic pain conditions had higher odds of difficulties with sleep, compared to those with persistent TBI alone, which remained significant after adjusting for serving status and military rank (OR = 1.96; 95% CI: 1.32-2.90). The overall prevalence of individuals who endorsed high sleep difficulties among

those with persistent TBI and chronic pain conditions was 63%. This is similar to recent evidence that found that 62% of individuals with comorbid TBI and chronic pain received sleep apnea diagnoses (Martin et al., 2023). Also, both TBIs and chronic pain conditions have individually been associated with poorer sleep (Lange et al., 2022; Mollayeva et al., 2015; Mumbower et al., 2019; Seal et al., 2017). Sleep difficulties after a TBI can be related to numerous factors, including one's lifestyle, mood changes, and pre-injury sleep habits; however, current evidence supports the hypothesis of a shared mechanism between secondary brain injuries post-TBI including neuroinflammation, and an increase in sleep disruptions or disorders that can become chronic and last for years (Herrero Babiloni, Baril, et al., 2023). Underlying brain mechanisms that experience dysfunction are also suggested to be involved in a bi-directional relationship between sleep and chronic pain, where poorer sleep after TBI could lead to chronic pain conditions, and vice versa (Herrero Babiloni, Baril, et al., 2023; Martin et al., 2023). Sleep is integral to one's recovery after injury. For patients with TBI, attention to sleep habits and sleep hygiene post-injury could help mitigate adverse and chronic outcomes, including the development of chronic pain conditions.

In addition to the above findings, moderation effects were hypothesized, such that significant interactions would be present for problem-solving coping, avoidant coping, self-medication coping, social support, and sleep difficulty with persistent TBI on any chronic pain condition(s). Our results demonstrated problem-solving coping to have a significant interaction effect with persistent TBI (problem-solving coping x persistent TBI) on any chronic pain condition(s), such that lower use of problem-solving coping strengthened the association between persistent TBI and any chronic pain condition(s). This interaction is supported by previous findings discussed above, where reductions in problem-focused coping has been observed among those after TBI and have been linked with adverse and prolonged outcomes, including chronic pain (Scheenen et al., 2017; Spitz et al., 2013). This interaction may have significant clinical implications regarding the recovery of those with persistent TBI and the development of chronic pain conditions. Providing military personnel with early education and resources that focus on adaptive coping, like problem-solving strategies, may help individuals better plan for their recovery and management of expectations and symptoms to help mitigate chronic TBI symptoms and associated morbidities, like chronic pain.

Strengths of Study

Strengths of the current study include the large and nationally representative dataset of CAF service members and veterans who were not recruited from a clinical, treatment-seeking sample. Therefore, these findings can provide a more accurate and representative picture of the overall burden of persistent TBI and chronic pain conditions in the CAF. Additional strengths include respondent interviews completed by trained-lay interviewers, mental health diagnoses based on structured diagnostics (i.e., WHO-CIDI), and an extensive survey offering a more comprehensive understanding of the relationship between persistent TBI and chronic pain conditions, including examination of mental health disorders, other biopsychosocial factors that have limited previous findings, and multiple chronic pain conditions.

Limitations of Study

There are several limitations of the proposed study. First, this was a secondary data analysis of previously collected data; therefore, analyses were restricted to the survey data that had already been collected, without option to obtain further data or tailor the questionnaire. As such, TBI assessment was limited to those who considered their TBI to be persistent (i.e., symptoms lasting for 6 months or longer); thereby limiting the generalisability of the findings to be applicable only to those with persistent TBI, in comparison to any TBI, which would include those whose outcomes may be more transient in nature. Analyses were similarly unable to examine potentially important details about persistent TBI(s), including the severity, duration, location of the injury, and number of TBI's experienced by the individual. Additionally, there was a lack of specific questions surrounding the experience or diagnosis of a more generalized chronic pain syndrome; therefore, this sample may not be inclusive and representative of all individuals who experience chronic pain.

Secondly, the current dataset resulted in limitations to understanding the exact temporal relationship between persistent TBI and chronic pain conditions. Respondents were asked about their first diagnosis and not specifically asked about the onset of the current condition they were experiencing; therefore, the timing of TBI and chronic pain conditions could not confidently be determined, thus limiting the ability to interpret and make reliable conclusions about the directionality of the relationships or causation.

Thirdly, this study largely focused on examining a sub-sample of individuals who had

endorsed experiencing current persistent TBI, which resulted in a smaller sample size for most analyses. The reduced sample size created limitations in the analyses where small cell sizes were experienced, for example the mental health disorders analysis used an overarching 'any mental health disorder' category due to small cell size concerns. However, sensitivity analyses were conducted, which demonstrated similar trends across all mental health disorders. The limited sample size also resulted in some findings having larger confidence intervals which may be indicative of unstable estimates; therefore, caution is warranted in interpreting the results. Future research is needed to replicate these findings using a larger sample size. Furthermore, the smaller population size also resulted in the inability to stratify the sample by serving status to observe potential differences between active-serving members and veterans in the CAF. Similarly, the number of females in the CAF has historically been disproportionately lower than males, which has made the examination of sex differences difficult to accomplish in the past. In this study, the disproportion of females to males was reflected in the sample of interest, with significantly lower numbers of females to males. This discrepancy, along with a smaller overall sample size, resulted in the inability to stratify the sample by sex (i.e., male vs. female); therefore, we were unable to determine if differences by sex were present among pre-injury characteristics, mental health disorders, and other biopsychosocial factors.

Lastly, the assessment of persistent TBI and chronic pain conditions was based on self-report measures. Therefore, the prevalence of these conditions may have been either overestimated or underestimated due to a self-reporting bias and therefore, warrant further research to replicate the findings and provide reliability.

Knowledge Translation

During the early planning phase of this study, knowledge translation activities commenced with the exchange of information with veterans with lived experience, military professionals, academic researchers, and clinicians during the Chronic Pain Centre of Excellence (CPCoE) for Veterans Research 2023 Conference in September 2023. At this conference, the study in its proposed stage was presented and discussed, with space for veterans with lived experience and others to share their feedback and considerations.

The goal is to disseminate the findings from this study to academic, clinical, and lay audiences alike, to provide a more thorough understanding of how persistent TBI affects CAF

members and veterans, especially those who experience co-occurring chronic pain conditions.

The first step in dissemination will include meeting with members of CPCoE, the Canadian Institute for Military and Veterans Health Research (CIMVHR), Veterans Affairs Canada (VAC), and the Department of National Defence (DND) to discuss the study findings, the implications, and how to best share and circulate this information to other researchers, clinicians, and CAF members and veterans. The target audience for this work includes clinicians who work with CAF members and veterans, military policy and decision-makers, researchers, and CAF members and veterans' themselves and their family members, who experience these conditions firsthand. Through the author's financial supporters, CPCoE and CIMVHR, dissemination support, including dissemination products and other opportunities for presentation and sharing, has been offered and will be acted upon after thesis completion. One possible option for presenting and sharing the findings across a large and diverse audience could include the creation of an infographic that would use lay language and provide easy to read visuals to present key research findings.

In addition, the dissemination plan includes connecting with the Operational Stress Injury (OSI) Clinic in Winnipeg, MB and arranging a time to present the study findings at one of their monthly research meetings. This would provide an opportunity to discuss the findings with their clinical staff who work directly with patients affected by persistent TBI and chronic pain conditions. Findings could be presented as both a short PowerPoint presentation, outlining key findings and the potential implications for intervention and treatment, and an infographic that describes the study and presents key findings using visuals in lay language for all audiences. As mentioned, support for knowledge translation product design and production has been offered by CPCoE.

The dissemination plan further includes the intent to present at both the annual CPCoE Stakeholder meeting and CIMVHR Forum. These conferences offer the opportunity to engage with researchers, clinicians, veterans with lived experienced, and policy makers within both academic and military environments. The presentation(s) could consist of a poster and/or PowerPoint slides. CPCoE and CIMVHR would provide social media support to engage and promote the presentation and publication of the findings from this study.

The final aim of dissemination includes publishing the thesis findings in a high-impact, peer-reviewed journal which will allow us to share findings across a wide range of audiences.

Chapter 5: Conclusions & Implications

Summary of Findings

In conclusion, the present findings expand upon the current literature, presenting novel associations between persistent TBI and multiple chronic pain conditions within a military population; moreover, this is the first study to examine chronic pain conditions among CAF members and veterans with persistent TBI. This thesis provided insight into the biopsychosocial relationship between persistent TBI and chronic pain conditions by including the examination of preinjury characteristics, mental health disorders, and other biopsychosocial factors. Individuals with junior non-commissioned ranking, veteran members (vs. active-duty), and those with lower use of problem-focusing coping and higher rated sleep difficulties were more likely to have chronic pain conditions among all CAF members with persistent TBI. Problem-solving coping was additionally found to moderate the relationship between persistent TBI and any chronic pain condition, where individuals with persistent TBI who had a lower endorsement of problem-solving coping showed a stronger association with any chronic pain condition(s). These findings suggest clinical implications that may be useful in the identification of individuals with persistent TBI who may be more likely to develop chronic pain conditions, as well as identifying key therapeutic targets that could benefit the recovery of these individuals.

Implications

The current study is a novel addition to the existing literature and is the first study, to date, to examine in detail the relationship between persistent TBI and chronic pain conditions among CAF active-duty members and veterans. Importantly, this research addressed gaps in the literature and added to the current knowledge in providing a better understanding of a more detailed relationship between persistent TBI and chronic pain conditions. Moreover, the unique dataset allowed for a more comprehensive examination of this relationship by examining a wide range of pre-injury characteristics (i.e., sociodemographic, and military demographics), as well as mental health disorders and other biopsychosocial factors, associated with this relationship.

The impact of a TBI on one’s life can be complex and long-lasting, with significant impairments and morbidities experienced at the emotional, physical, biological, and social level

(Dams-O'Connor et al., 2023). Military personnel with TBI have commonly experienced high employment instability, increased healthcare visits, and healthcare costs, which are further heightened by co-occurring chronic pain, in comparison to those with TBI alone (Hoot et al., 2018). This study provided awareness into the significantly higher prevalence of chronic pain conditions among CAF members experiencing persistent TBI, compared to those without persistent TBI; 85.7% vs. 59.7% respectively. These findings further provided an understanding of the significantly increased odds of experiencing specific co-occurring chronic pain conditions among those with persistent TBI in comparison to those without. This was the first study among CAF personnel and veterans to demonstrate the increased prevalence and heightened odds of arthritis (55.2% vs. 32.2%), back problems (71.6% vs. 43.6%), migraine headaches (30.9% vs. 9.6%), and gastrointestinal conditions (25.9% vs. 9.4%) among those with persistent TBI compared to those without persistent TBI.

These findings, while unable to speak to a temporal relationship, indicate that assessment of chronic pain comorbidities may be warranted among individuals experiencing persistent effects of TBI and could help reduce further symptoms and overall disability. The high comorbidity of chronic pain conditions demonstrated in this study similarly supports the promotion and use of interdisciplinary teams of healthcare professionals that would make it possible to address the complex and heterogenous sequelae associated with persistent TBI, inclusive to a variety of chronic pain conditions (Bosco et al., 2013). The addition and early use of pain care management into the recovery and rehabilitation of SMs and veterans post-TBI could help to mitigate the experience of comorbid chronic pain conditions through targeted treatment and intervention efforts. The utility and feasibility of interdisciplinary pain management programs for veterans in Canada has so far been shown to be successful; providing a space for veterans to better manage their outcomes and to feel understood (Thompson et al., 2020). However, interdisciplinary healthcare, and particularly pain clinics, may not be available or accessible across Canada. Furthermore, treatment for those who have transitioned into civilian life is often lacking the incorporation of and sensitivity to military cultural competence, which has been expressed as an important factor for veterans seeking help (Armistead-Jehle et al., 2017).

The examination into preinjury characteristics highlighted key military demographics associated with experiencing co-occurring persistent TBI and chronic pain conditions and may

help delineate which groups are at particular risk for developing chronic pain conditions. Specifically, the findings highlighted CAF members with junior non-commissioned ranking and veteran serving status to be at significantly higher risk for comorbid chronic pain conditions. These findings have implications for both clinicians and decision-makers, where attention to specific military characteristics among CAF personnel may be helpful for identifying higher risk individuals post-TBI.

Results of this study provide insight into the prevalence of comorbid mental health disorders and other biopsychosocial factors that may be involved in the relationship between persistent TBI and chronic pain conditions. The findings serve to help inform the planning of improved treatment and intervention strategies with the aim of reducing the likelihood of developing further negative or lasting consequences post-TBI. In particular, the attention to potentially modifiable biopsychosocial factors, like coping strategies and sleep habits, that were significantly associated with co-occurring persistent TBI and chronic pain conditions may be useful in reducing adverse and long-lasting outcomes. Targeted interventions that encourage the use of problem-focused coping strategies may help reduce the likelihood of developing chronic pain conditions among CAF personnel with TBI. Therapeutic interventions, like cognitive behaviour therapy (CBT), that incorporate building adaptive coping skills and bring awareness to the link between one's thoughts, feelings, and behaviours, have been shown to be useful for the management of chronic pain, fatigue, and sleep disorders (Khoury & Benavides, 2018; Polinder et al., 2018; Rakers et al., 2021). Providing CBT-based education and support to CAF members early in their careers could be an essential up-stream approach that could be helpful in mitigating future negative symptoms (i.e., mental health, sleep) throughout their careers and after transition to civilian life. Other forms of intervention that could be helpful and have been shown to be beneficial for management of chronic symptoms of TBI and pain conditions include mindfulness, yoga, and other forms of exercise (e.g., swimming, t'ai chi, strength training) (Cohen et al., 2021; Khoury & Benavides, 2018; Mills et al., 2019).

To summarize, the findings of this thesis support the promotion and use of an integrative and multi-symptom, stepped-care approach to managing persistent TBI and chronic pain conditions that is focused on the whole-person. This can be accomplished using interdisciplinary teams of healthcare professionals (i.e., neurologists, pain specialists, mental health professionals) to address the myriad of negative symptoms and comorbidities commonly experienced by those

with persistent TBI, including chronic pain conditions and mental health disorders, from a biopsychosocial perspective. Early identification of chronic pain conditions is key, especially for individuals with persistent TBI, where symptom profiles may be overlapping and difficult to distinguish between. Furthermore, education and interventions that can help build and foster the use of adaptive skills, like problem-solving coping and proper sleep hygiene, may improve the attitudes and resilience of CAF members and give them the skill set needed to better deal with their physical and emotional health.

These findings may also be an integral source of information for CAF active-duty members, veterans, and their families who have previously been noted to be under- or mis-educated about TBIs (Armistead-Jehle et al., 2017). This work could provide individuals with a better understanding and awareness of potential comorbid outcomes post-TBI, and the complexity and chronicity of this symptom profile. A better expectation of symptoms that could be experienced, and an awareness of potential therapeutic targets or initiatives could allow individuals to be more in control of their recovery and to better advocates for themselves and their loved ones.

Future Directions

There is a need for future research that can help to address the remaining gaps and inconsistencies in understanding the relationship between persistent TBI and chronic pain conditions among military personnel, by replicating and expanding upon the results of this study and that of previous work. More specifically, there is a need for future longitudinal studies that can examine the temporal, and potentially causal, relationship between persistent TBI and the development of comorbid chronic pain conditions using a large study sample, with a diverse military population inclusive of sex, gender, and serving status (i.e., active-duty vs. veteran). Future research should look to examine the long-term outcomes of all CAF members post-TBI, where attention could also be focused on differences in outcomes by characteristics that include acute vs. chronic TBI, single vs. repeated TBI, mental health comorbidities, and other biopsychosocial factors like coping and sleep. There is also a need to better understand the relationship between coping styles and post-TBI outcomes including the development and maintenance of chronic pain conditions. For example, identifying whether the use of CBT-based

psychotherapy with coping skills, could help reduce symptoms of both TBI and chronic pain conditions. Furthermore, concurrently studying the brain, for instance, scanning the brain before and after a CBT-based intervention, could provide insight into potential changes in shared mechanisms underlying chronic TBI and pain condition symptoms and could help to inform future intervention efforts.

The findings from this study have brought attention to a remarkably high prevalence of comorbid chronic pain conditions experienced among CAF members with persistent TBI. It is clear that future work is needed to better understand this relationship, including examination into causality, overlapping symptoms, comorbidities, and common mechanisms, to better inform assessment, prevention and intervention efforts.

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Table 1

Chronic Pain Conditions (i.e., Arthritis, Back Problems, Migraine Headaches, and Gastrointestinal Conditions) Among CAF Members With and Without Persistent TBI

Chronic Pain Condition	% (95% CI) No Persistent TBI	% (95% CI) Persistent TBI	OR (95% CI)
Arthritis	32.2 (30.3-34.2)	55.2 (47.0-63.1)	**2.59*** (1.84-3.65)**
Back Problems	43.6 (41.4-45.7)	71.6 (63.3-78.7)	**3.27*** (2.20-4.87)**
Migraine Headaches	9.6 (8.4-10.9)	30.9 (23.8-39.0)	**4.21*** (2.83-6.26)**
Gastrointestinal Conditions (IBD/IBS/ulcer/colitis)	9.4 (8.3-10.6)	25.9 (19.2-33.9)	**3.37*** (2.23-5.09)**
Any chronic pain condition(s)	59.7 (57.6-61.7)	85.7 (78.5-90.8)	**4.06*** (2.42-6.80)**

Note. This table examines chronic pain conditions among CAF members with persistent TBI in comparison to those without persistent TBI.

Abbreviations: TBI, traumatic brain injury; CI, confidence interval; OR, odds ratio; IBD, irritable bowel disease; IBS, irritable bowel syndrome.

Bold font indicates statistical significance. *$p < .05$. **$p < .01$. ***$p < .001$

Table 2

Preinjury Characteristics among CAF Members with Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

	% (95% CI)		
Preinjury Characteristics	**Persistent TBI, alone**	**Persistent TBI with Chronic Pain**	**OR (95% CI)**
Biological Sex			
Male	88.0 (76.4-94.3)	89.6 (85.7-92.6)	-
Female	*12.0* (5.7-23.6)	10.4 (7.4-14.3)	0.85 (0.35-2.03)
Marital Status			
Partnered	85.4 (62.2-95.4)	88.1 (81.3-92.6)	-
Unpartnered	*14.6* (4.6-37.9)	11.9 (7.4-18.7)	0.79 (0.15-4.13)
Household Income			
$0 – $89,999	*22.4* (9.5-44.5)	35.0 (26.4-44.5)	-
$90,000 and over	77.6 (55.5-90.5)	65.0 (55.5-73.6)	0.54 (0.16-1.86)
Education Status			
high school diploma or less	*46.9* (26.2-68.8)	47.5 (37.9-57.3)	-
at least some secondary	53.1 (31.2-73.8)	52.5 (42.7-62.1)	0.98 (0.35-2.74)
Rank			
Junior non-commissioned member	*16.8* (5.8-39.8)	49.7 (40.8-58.6)	-
Senior non-commissioned member	50.4 (29.6-71.0)	39.6 (31.0-48.9)	0.27 (0.06-1.19)
Officer grouping	32.8 (16.5-54.7)	10.7 (6.9-16.3)	**0.11** (0.23-0.53)**
Serving Status			
Non-veteran	*47.4* (26.4-69.4)	19.5 (13.2-27.9)	-
Veteran	52.6 (30.6-73.6)	80.5 (72.1-86.9)	**3.72* (1.25-11.10)**

Table 2. *(continued)*

Environment Uniform					
Air	14.3 (6.4-29.0)		23.6 (16.3-32.8)		1.36 (0.43-4.26)
Land	*50.7* (29.9-71.4)		61.7 (51.9-70.6)		-
Sea	*34.9* (17.1-58.3)		14.7 (9.3-22.5)		0.35 (0.95-1.26)
Deployment					
Never deployed	*20.6* (8.2-42.9)		11.3 (6.9-18.1)		-
Deployed	79.4 (57.1-91.8)		88.7 (81.9-93.1)		2.03 (0.56-7.41)
	Mean	**SE**	**Mean**	**SE**	**OR (95% CI)**
Age	45.9	42.2-49.5	49.8	48.4-51.2	1.07 (.99-1.16)

Note. This table examines preinjury characteristics among CAF members with persistent TBI and chronic pain conditions in comparison to those with persistent TBI alone (no chronic pain conditions).

Abbreviations: TBI, traumatic brain injury; CI, confidence interval; OR, odds ratio; SE, bootstrapping standard error.

Bold font indicates statistical significance. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 3

Mental Health Disorders Among CAF Members With Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

	% (95% CI)			
	Persistent TBI, alone	Persistent TBI with Chronic Pain Condition	OR (95% CI)	AOR[A] (95% CI)
Any mental health disorder				
No	46.4 (25.3-68.9)	*31.9* (24.1-40.8)	-	-
Yes	53.6 (31.1-74.7)	68.1 (59.2-75.9)	1.85 (0.62-5.49)	1.60 (0.52-4.95)

Note: This table examines mental health disorders among CAF members with persistent TBI and any chronic pain condition(s) in comparison to those with persistent TBI alone (no chronic pain conditions).
Any mental health disorder includes depression, posttraumatic stress disorder, generalized anxiety disorder, panic disorder, social phobia, and alcohol use disorder.

Abbreviations: OR, odds ratio; CI, confidence interval; AOR; adjusted odds ratio; TBI, traumatic brain injury

[A] Adjusted by significant preinjury characteristics (i.e., rank and serving status)

Bold font indicates statistical significance. **p* < .05. ***p* < .01. ****p* < .001.

Table 4

Biopsychosocial Factors among CAF Members With Persistent TBI and Chronic Pain Conditions vs. Persistent TBI Alone

	% (95% CI)			
Biopsychosocial Factors	Persistent TBI, alone	Persistent TBI with Chronic Pain	OR (95% CI)	AOR[A] (95% CI)
Problem-Focused Coping				
Low	52.3 (31.6-72.2)	79.1 (71.0-85.4)	-	-
High	47.7 (27.8-68.4)	20.9 (14.6-29.0)	**0.29* (0.10-0.80)**	0.86 (0.65-1.14)
Avoidant Coping				
Low	47.8 (26.1-70.4)	40.2 (31.2-49.9)	-	-
High	52.2 (29.6-73.9)	59.8 (50.1-68.8)	1.37 (0.46-4.07)	1.09 (0.93-1.28)
Self-Medication Coping				
Low	67.0 (41.3-85.4)	61.3 (51.9-70.1)	-	-
High	33.0 (14.6-58.7)	38.7 (30.0-48.2)	1.28 (0.37-4.40)	1.09 (0.81-1.48)
Social Support				
Low	54.9 (33.3-74.8)	59.9 (50.5-68.6)	-	-
High	45.1 (25.2-66.7)	40.1 (31.4-49.5)	0.81 (0.29-2.25)	0.97 (0.92-1.03)
Moral Injury				
Low	19.8 (8.4-39.9)	26.3 (18.9-35.5)	-	-
High	80.2 (60.1-91.6)	73.7 (64.5-81.1)	0.69 (0.21-2.29)	0.98 (0.94-1.02)
Sleep Difficulty				
Low	86.2 (66.2-95.2)	37.0 (28.3-46.5)	-	-
High	13.8 (4.8-33.8)	63.0 (53.5-71.7)	**10.67*** (3.02-37.64)**	**1.96*** (1.32-2.90)**

Table 5. *(continued)*

Note: This table examines biopsychosocial factors among CAF members with persistent TBI and any chronic pain condition(s) in comparison to those with persistent TBI alone (no chronic pain conditions).

Abbreviations: OR, odds ratio; AOR, adjusted odds ratio; TBI, traumatic brain injury.

[A] Adjusted by significant preinjury characteristics (i.e., rank and serving status)

Bold font indicates statistical significance. *$p < .05$. **$p < .01$. ***$p < .001$