THE RELATIONSHIP BETWEEN PARITY STATUS AND MUSCULOSKELETAL INJURY PREVALENCE IN FEMALE MEMBERS OF THE CANADIAN ARMED FORCES

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Abstract

Musculoskeletal injuries (MSKi) place a significant burden on females in arduous occupations, like military service members, first responders (public safety personnel), and healthcare workers. In the Canadian Armed Forces (CAF), females are more likely to release due to an MSKi than their male peers, and male healthcare workers demonstrate a lower relative risk for all injuries. Female reproductive health (*e.g.,* pregnancy) may contribute to the sex-disparities in MSKi prevalence, but the relationship between parity status and MSKi has not been explored. The multistage approach applied to examine the relationship between parity status and MSKi in CAF members was as follows: *i)* Self-reported MSKi and reproductive health data were collected via an online questionnaire and analyzed using chi-square and logistic regression tests. *ii)* Physical testing to assess flexibility (sit-and-reach), muscular power (long jump and medicine ball throw), movement competency (bodyweight overhead squat test), muscular strength (4 repetition maximum back squat and bench press), muscular endurance (Biering-Sorenson test, single-leg wall sit, and push-ups), aerobic capacity (graded treadmill VO_{2max} test). MSKi history and reproductive health data were collected via a pre-screening questionnaire. Physical fitness was compared by parity status and MSKi history using one and two-way analysis of variance (ANOVA) tests. *iii)* A study similar to step *ii* was conducted in females employed as first responders or healthcare providers. *iv)* A 3-way ANOVA was performed to compare the CAF and non-military samples from steps *ii* and *iii*. Parous CAF members were more likely to sustain repetitive strain injuries (overall and at the wrist and foot) compared to nulliparous peers. When matched for injury history, parous CAF members performed better in upper body muscular endurance, lower back muscular endurance, and lower body muscular strength. Conversely, the parous group in the non-military study participants demonstrated inferior performance in lower body power, lower back endurance, and lower body and upper body strength. Parity

status should be considered independently and in conjunction with MSKi when developing support initiatives for females employed in both military and non-military contexts, however, given the opposing findings regarding fitness performance, research specific to the CAF is needed to inform policy and evidence-based practice.

Co-Authorship and Formatting Note

A contribution statement for authors involved in each study included in this thesis is included in the title page for each chapter.

Please note that each chapter's formatting reflects the requirements of the journal in which each manuscript was published or submitted. Therefore, multiple citation and formatting styles are included within this document.

Dedication

This thesis is dedicated to the members of the Canadian Armed Forces, public safety personnel, and health care providers who devote their lives to protecting others. You inspire and motivate me to be better, to be relentless in the pursuit of the objective. I am deeply humbled and honoured to be able to support you. Thank you for doing what you do.

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List of Abbreviations

4CDSG, 4th Canadian Division Support Base Petawawa

4RM, Four repetition maximum

AI, Acute injuries

ANCOVA, Analysis of covariance

ANOVA, Analysis of variance

aOR, Adjusted odds ratios

BC, Birth control

BIA, Bioelectrical impedance analyzer

BMD, Bone mineral density

BMI, Body mass index

CA, California

CAF, Canadian Armed Forces

CFB, Canadian Forces Base

CI, Confidence intervals

Cm, Centimeters,

DND, Department of National Defence

DXA, Dual-energy X-ray absorptiometry

FORCE, Fitness for Operational Requirements of Canadian Armed Forces Employment

FR, First responder

GDM, Gestational diabetes mellitus,

GXT Graded treadmill exercise test

HCP, Healthcare providers

HR, Heart rate

IDEaS, Innovations for Defence Excellence and Security

IUGR, Intrauterine growth restriction.

Kg, Kilograms

L, Left

lbs., Pounds

LPHC, Lumbopelvic hip complex

M, Meters

Min, Minutes

MKD, Medial knee displacement

mL, Milliliters

MSKi, Musculoskeletal injuries

NCM, Non-Commissioned Member

NM, Non-military

OHS, Bodyweight overhead squat

PT, Physical training

QC, Quebec

R%, Bodyweight / absolute weight lifted in RM

RCAF, Royal Canadian Air Force

RCN, Royal Canadian Navy

Reps, Repetitions

RER, Respiratory exchange rate

RM, Repetition maximum

RPE, Rate of perceived exertion

RSI, Repetitive strain injuries

RSI, Repetitive strain injuries

Rt, Right

SD, Standard deviation

SDC, Supplemental digital content

Sec, Seconds

UB, Upper back

UK, United Kingdom

US, United States

US, United States of America

VO_{2max}, Maximal oxygen uptake

Preface

Title: A history of childbirth as a potential risk factor for musculoskeletal injury in military personnel

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Pregnancy has a substantial impact on one's body and subsequent life. Whether these changes increase injury risk after returning to sport or work in both short and long-term remains unclear. It is becoming evident that reproductive health should be considered in research and practice to ensure the physical well-being of females employed in arduous occupations such as military, public safety personnel (i.e., law enforcement, paramedicine, firefighting), or healthcare. As the transition period after maternity leave is a common attrition point for female members in the military, which could be due to a lack of physical rehabilitation support when returning to duty, (1) we discuss the similarities between musculoskeletal injury (MSKi) and pregnancy.

Among the strongest predictors of future injury is previous MSKi. Tissues of the musculoskeletal system adapt to stimuli (i.e., mechanical or chemical), improving functional ability; however, when the damage caused by the stimulus exceeds the remodeling capacity of the body, injury occurs. Severe trauma to muscles, tendons, ligaments, and bones can result in altered tissue plasticity and significant disability for years after the initial incident. As childbirth is a substantial musculoskeletal event, it may intensify MSKi risk, and specific MSKi have been linked with pregnancy. Carpal tunnel syndrome, for example, a repetitive strain injury involving the wrist, affects approximately 17% of parous individuals.(2) Despite known relationships, the literature examining health outcomes, including MSKi, after pregnancy in athletes and females employed in arduous occupations is minimal. Ultimately, the numerous anatomical, biomechanical, and physiological changes occurring during pregnancy and the postpartum period present critical time points of musculoskeletal system vulnerability, which could increase injury susceptibility.(1)

Anatomical adaptations in pregnancy include; alterations in the spinal curvatures (i.e., increases in the lumbar lordosis), change in center of mass, and stretch in the abdominal musculature up to 115% of resting length by the end of the third trimester.(3) During labour and delivery, the pelvic floor muscles stretch to 250% of resting length, and varying degrees of tissue tearing occurs.(3) The muscular adaptations throughout gestation and damage at delivery likely contribute to the biomechanical changes observed throughout pregnancy and postpartum. For example, peak hip abductor moments through gait are higher during and after pregnancy, possibly related to diminished gluteus maximus activation amplitude seen through the second trimester and postpartum period.(4) Altered knee and ankle kinematics, in addition to differences in total work through gait, also present through the third trimester and postpartum period.(4)

Similar to pregnancy and postpartum, long-lasting compensatory movement patterns occur after MSKi.(5) For instance, anterior cruciate ligament reconstruction in athletes yields differences in knee kinetics and kinematics beyond the return-to-play time frame.(5) The adaptations to knee injury cause deficits in running mechanics, conceivably adding strain to the uninjured leg. Such movement pattern changes may connect previous injuries to future MSKi.

Pregnancy and childbirth are significant musculoskeletal events that result in compensations akin to those of MSKi. As a history of tissue trauma is a strong predictor of MSKi, parity status should be explored as a risk factor for injury.

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Chapter 1

Introduction

The first time women served in a military setting for Canada was the North-West Rebellion in 1885.[1] Military service was open to women periodically through the 1900s until Parliament passed the Canadian Human Rights Act and the Canadian Charter of Rights and Freedoms. In 1985, women were permitted to serve in all trades except on submarines (opened in 2001). [1] Since then, women have increased their presence among the ranks, though representation remains low at 15%.[2]

Under *Strong, Secure, Engaged:* Canada's Defence Policy, outlined a goal of 25.1% representation of women by 2026.[2] Initiatives aimed at retention and recruitment of women have already identified musculoskeletal injuries (MSKi) as a leading cause of medical release and overall attrition.[2-5] While MSKi do not exclusively impact women and females; females are more likely to medically release from the CAF due to MSKi when compared to their male counterparts.[5] In a 2020 report (non-peer reviewed) by Guerin *et al.*, repetitive strain injury (RSI) and acute injury were reported at similar rates between males and females.[4] However, these findings differ from reports from other nations, where being female is frequently cited as a risk factor for MSKi in both active military and recruits.[4,6,7] Proposed factors contributing to the increased risk in females compared to males are muscle activation patterns, anatomical structure, hormone differences, including those associated with the menstrual cycle, and other events associated with female reproduction (e.g., pregnancy and the postpartum).[8]

Pregnancy and postpartum: Anatomical, physiological, and biomechanical changes

Given that the majority of female CAF members are of childbearing age, examination of female reproduction as a risk factor for MSKi is warranted.[9,10] Pregnancy causes numerous anatomical, biomechanical, and physiological changes that can persist beyond the postpartum period.[11-15] For example, relaxin, a hormone that increases ligament laxity found in both sexes, circulates at much higher levels in females, and even more so with pregnancy.[8] Higher levels of circulating relaxin could make joints vulnerable to injury.[8,11] Anatomically, the positioning and shape of skeletal structures and pelvic organs shift throughout pregnancy.[16] This includes alterations in the spinal curvatures, like increases in the lumbar lordosis.[17] Additionally, several changes can occur in the foot during pregnancy (i.e., length, width, volume), and altered plantar pressure distribution during gait has been observed.[12,13,15,18,19] The changes in the foot can persist after childbirth and are attributed to increases in body mass and endocrine system responses to pregnancy.[19,20] The pregnancy-related anatomical alterations may contribute to biomechanical changes in gait that occur throughout gestation.[11] Gluteus maximus activation amplitude is significantly less starting in the second trimester and persists into the postpartum period.[11] Compared to nulliparous controls, greater knee abductor, ankle plantar flexor, and dorsiflexor moments are seen through the third trimester and postpartum period.[11] Evidence indicates some of these changes, specifically work demands of walking, may be due to increased bodyweight, not pregnancy alone.[21] Whether it be pregnancy or factors that can present during gestation (e.g., weight gain), investigation of the lasting effects and breadth of these changes may help guide exercise programs to mitigate fitness performance deficits and injury risk.

Movements other than gait may be impacted through pregnancy and the postpartum period as demonstrated by the decreases in multiplanar knee laxity and increases in anterior compliance, when comparing early pregnancy to approximately 5 months postpartum.[22] This rapid change in kinematics may not permit strength adaptations, making tissues vulnerable to overuse injury. Further, the knee and ankle kinematic changes, combined with altered muscle activation at the hip, suggest that parous females may be more likely to experience dynamic knee valgus in movements like the squat.[11,22-24]

Evidence supports dynamic knee valgus as a risk factor for MSKi and patellofemoral pain syndrome.[25,26] Comparing movement patterns, like dynamic knee valgus, of parous and nulliparous females, could help explain why physiological, anatomical, and biomechanical shifts resulting from pregnancy are often concurrent with bodily pain (e.g., lower back reported by up to 95% of pregnant women in some populations) and possibly injury.[17,27]

Musculoskeletal injury and pregnancy

Specific MSKi have been linked with pregnancy.[32-34] Carpal tunnel syndrome, an RSI involving the wrist, is one example.[32] A literature review performed by Padua *et al.* (2010) found that pregnancy-related carpal tunnel syndrome affected approximately 17% of research participants. Padua *et al.* (2010) also noted that most pregnancy-related carpal tunnel syndrome cases appear to resolve spontaneously within one to three years.[33,35] Bone fracture risk may also be elevated in the postpartum period due to a 3%-10% loss in bone mineral density during lactation.[27] Collectively, pregnancy and the postpartum period represent critical time points regarding musculoskeletal system vulnerability that may cause parous CAF members to have different injury profiles than their nulliparous peers.

Pregnancy and postpartum in the military context

The relationship between pregnancy or parity status on injury or performance is largely unexplored in both sport and military contexts. A recent review and meta-analysis examining health outcomes after pregnancy in elite athletes found only “very low” and “low” quality evidence exploring the link between pregnancy and MSKi, highlighting a need for further research in this area.[36] In the United Kingdom (UK) Armed Forces, where servicewomen can return to duty as early as 2 weeks after giving birth, illness, and injury days are higher postpartum than pre-pregnancy.[27,37] Decreases in physical fitness test performance after childbirth have been observed in servicewomen of the United States (US) Army, Air Force, and Navy.[38-40] Low physical fitness scores are a risk factor for MSKi in military personnel, and the decline in physical performance may contribute to the threat of injury for female service members.[41,42] This fitness deficit can be reversed with sufficient physical training, as demonstrated by the international elite running community.[43,44] The majority of elite runners, who choose to return to sport after childbirth, achieve or exceed pre-pregnancy performance within 1-3 years of delivery.[43]

Females with careers in arduous occupations and sport

A recent opinion article written by various experts in the fields of military medicine and pregnancy highlights the absence of evidence surrounding fitness and exercise during pregnancy and postpartum in arduous occupations.[37] In the review, Jackson *et al.,* (2022) describe arduous occupations to be careers that have high physical demands such as servicewomen, elite athletes, and manual labourers. The authors conclude that insufficient evidence is available to form best practice recommendations for the care of pregnant or postpartum elite athletes or personnel in arduous occupations.[37] As initiatives targeting this knowledge gap begin, it would be beneficial to identify if research conducted on females working in military and non-military tactical or emergency response occupations can be used interchangeably. Personnel in military and non-military arduous occupations are often grouped together in the literature due to the perceived similarity in job demands.[37,45] A direct comparison of physical fitness or injuries within these groups is not currently available in the literature.

Thesis objectives

In Canada, female representation in arduous occupations (for the purpose of this thesis, defined as an occupation that has clearly described physical fitness requirements within the hiring criteria and may include a minimum physical employment standard test [*i.e.*, firefighting, law enforcement, paramedicine, healthcare and military]) is gradually increasing, however, these individuals are tremendously underrepresented in the literature.[10,46] Further, the number of female individuals choosing to continue careers after childbirth is rising in Canada.[18] The lack of data on MSKi and parity status gathered on females in these occupations limits the ability of policy-makers to create evidence-informed strategies and programs to offset the burden of these factors. What has been identified in female CAF membership is that the two principal time points for attrition are i) following an MSKi, and ii) following childbirth.[47] Thus, the goals of the studies included in this thesis are: *i)* explore parity status as a risk factor for MSKi in female CAF members, *ii)* compare physical fitness in parous and nulliparous CAF members with a history of MSKi, *iii)* examine the relationship between parity status, and MSKi with physical fitness performance in non-military arduous occupations, and *iv)* provide a direct comparison of physical fitness between CAF and Canadian non-military personnel while considering parity status and a history of MSKi. The final aspect of this project, comparing CAF members with non-military personnel, will point to similarities and differences between populations. This comparison could indicate if data on these groups can be combined to guide future policy and research initiatives.

CHAPTER 2 PREAMBLE

An important first step to examining the relationship between MSKi and parity status, is to first identify if the injuries being experienced by female CAF members who have given birth are different compared to members who have not. This chapter examines physical health (including injuries) and mental health in relation to parity status, pregnancy related complications, and specialized support through pregnancy and the postpartum period. The findings in this chapter are used to inform Chapter 3 and 4.

Chapter 2

Parity Status and Injury in Military Personnel

Study title: Does a history of childbirth impact injury prevalence and mental health in female military members?

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Contributions:
CME, DFdS, SCS, KS, and KBA created the questionnaire used for this study.
Data cleaning was performed by CME, DFsS, SCS, and JP. Data analysis for this study was performed by CME. DFdS and KBA lead the project in which this study was included, with funding grant was procured by KBA, DFdS, KS. All authors contributed to the design of the study, revised, edited, read, and approved the final version of the manuscript.

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CHAPTER 2 SUMMARY INFOGRAPH

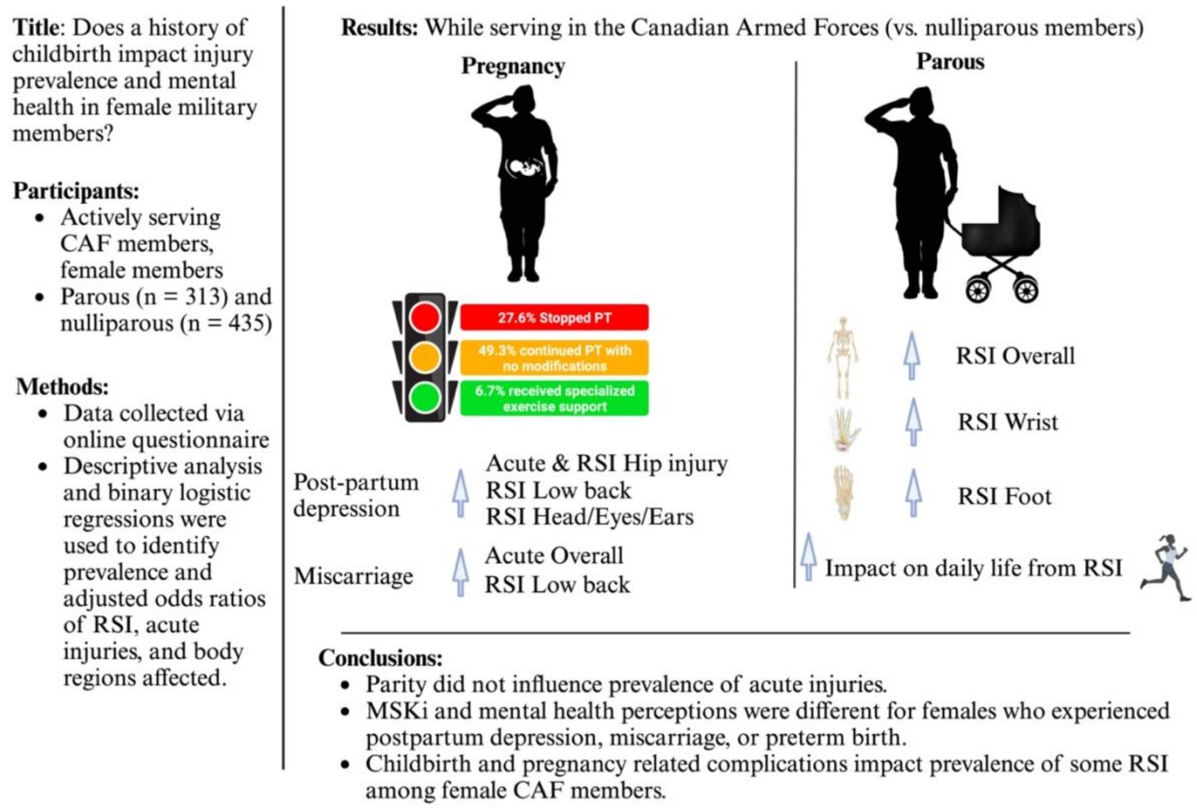

Figure 2.0 Visual summary of *Project 1 Does a history of childbirth impact injury prevalence and mental health in female military members?*. CAF = Canadian Armed Forces, RSI = repetitive strain injuries, MSKi = musculoskeletal injuries, PT = physical training.

ABSTRACT

The effect of parity status on the prevalence and impact of musculoskeletal injury (MSKi) among female Canadian Armed Forces (CAF) members is unknown. This study aims to identify whether a history of childbirth and pregnancy-related complications are associated with MSKi occurrence among female members of the CAF. From September 2020 to February 2021, data were collected via an online questionnaire that assessed MSKi, reproductive health, and barriers to recruitment and retention in the CAF. Actively serving, female members were included in this analysis stratified by parous (n = 313) or nulliparous (n = 435) status. Descriptive analysis and binary logistic regressions were used to identify prevalence and adjusted odds ratios (aOR) of repetitive strain injuries (RSI), acute injuries, and body regions affected. Covariates included in aOR: age, body mass index, and rank. A p-value <0.05 was considered significant and 95% confidence intervals (CI) were reported. Female members with a history of childbirth were more likely to report an RSI (80.9% vs. 69.9%, OR:1.57, CI:1.03;2.40), and when stratified by body region, were more likely to have an RSI of the wrist (30.0% vs. 20.5%, aOR:1.62, CI:1.09;2.40), and foot (39.3% vs. 24.1%, aOR:1.79, CI:1.24;2.59). When compared to the nulliparous group, parity did not influence prevalence of acute injuries. MSKi and mental health perceptions were different for females who experienced postpartum depression, miscarriage, or preterm birth. Childbirth and pregnancy related complications impact prevalence of some RSI among female CAF members. Thus, specific health and fitness support may be needed for parous female CAF members.

KEYWORDS: Women's health, pregnancy, female soldier, postpartum, army, air force, parity status

INTRODUCTION

Musculoskeletal injuries (MSKi) continue to present a significant threat to mission effectiveness and readiness of the Canadian Armed Forces (CAF)(Guerin, 2020). MSKi are one of the top causes for early release for both sexes, though compared to males, female CAF members are more likely to medically release due to MSKi (Serré, 2019). Recent data suggests females and males experience different injuries within the same CAF occupational roles (Edwards, 2021, Edwards et al., 2022). Proposed factors contributing to the increased risk in females compared to males are muscle activation patterns, anatomical structure, hormone differences, including those associated with the menstrual cycle, and other events associated with female reproduction (e.g., pregnancy and the postpartum) (Wolf et al., 2015).

Pregnancy and childbirth are accompanied by a plethora of physiological changes (Bagwell et al., 2020, Christopher et al., 2022, Vico Pardo et al., 2018, Wetz et al., 2006, Barakat et al., 2015, Mottola, 2008). For example, there are dramatic hormonal changes and the concentration of relaxin, a reproductive hormone, is significantly higher during pregnancy (Wolf et al., 2015). As the name suggests, the main function of relaxin is to relax pelvic floor structures in preparation for labour; however, it has a secondary impact on all muscles, ligaments, and joints. Thus, the physiological changes to connective tissues caused by relaxin during pregnancy could be contributing to childbirth as a risk factor for MSKi (Wolf et al., 2015, Bagwell et al., 2020).

The literature is sparse around the influence of pregnancy and a history of childbirth on MSKi risk in military personnel (Sammito et al., 2021, Kimber et al., 2021, Bø et al., 2016). A recent review and meta-analysis examining health outcomes after pregnancy in elite athletes found no randomized control trials and only “very low” and “low” quality evidence exploring the link between pregnancy and MSKi, highlighting a need for further investigation in this area (Kimber et al., 2021). A small body of research conducted on the general population suggests that repetitive strain injuries (RSI) specifically related to pregnancy do occur, but the mechanisms remain unclear (Padua et al., 2010). In the occupation context, a study comparing civilian female surgeons to non-surgeons, demonstrates that vocation can influence MSKi and pregnancy-related complications (Rangel et al., 2021). The conflict between work and home life may help explain these findings and poses a risk for long-term career impact (i.e., workplace satisfaction, career longevity) (Rangel et al., 2021, Dyrbye et al., 2012). To the best of our knowledge, similar investigations examining negative health outcomes relating to pregnancy have not been conducted on military personnel. The United States and the United Kingdom have examined congenital malformations, stillbirth, and miscarriage in Gulf war veterans, and more recently the Iraq war, but the focus of these inquests was to determine if combat deployment increased risk of miscarriage and fecundity (Doyle et al., 2004, Ippolito et al., 2017). Pregnancy-related complications, as well as the relationship between parity status and career-related implications, remain largely unexplored in military populations.

Psychological wellbeing must also be considered when discussing health of female personnel as pregnancy and physical injury increase the risk of poor mental health conditions (Colantonio et al., 2010, Chin and Zeber, 2019, Bedaso et al., 2021). Additionally, injury history correlates with psychological wellbeing during and after pregnancy. For example, pre-pregnancy history of mild traumatic brain injury has been associated with poor maternal mental health in the postpartum and impacts sex-hormone concentrations which could impact fertility and birth (Colantonio et al., 2010). Pregnancy-related mental health conditions such as perinatal depression and postpartum depression are known to be more prevalent in United

States servicewomen than the civilian population (Klaman and Turner, 2016). Associations between maternal mental health, pregnancy-related complications, and MSKi may be important considerations for the CAF population.

Investigating the burden of MSKi on female CAF members who have given birth (parous) and those who have not (nulliparous) is imperative to inform prevention initiatives and optimize health care. Uncovering risks of pregnancy and injury may be of value for other military organizations since studies exploring this association in servicewomen are yet to be explored. The purpose of this study is to investigate the *i*) impact of parity status (parous or nulliparous) on MSKi and career-related outcomes, *ii)* relationship between pregnancy-related complications (physical and psychological factors) and MSKi in female CAF members.

METHODS

Participants and Data Collection

From September 2020 to February 2021, data for this cross-sectional study were collected via a questionnaire developed as part of the "*multi-stage approach to addressing sex-disparities in musculoskeletal injuries in military members*" research project. The overarching aims of the questionnaire were to characterize MSKi risk, reproductive health, and barriers to recruitment and retention of females in the CAF. The inclusion criteria for the questionnaire were: being a member of the CAF (past or present), and between the ages of 18-65 years. Recruitment was conducted by the research team and project stakeholders via posters, social media, newsletters, and snowball methods. The questionnaire was accessed, and informed consent provided via the online cloud-based survey development software SurveyMonkey Inc. (San Mateo, USA).

A total of 2,001 participants provided consent and completed the SurveyMonkey questionnaire. For the present study, the inclusion criteria were: Regular or Reserve, being female, and being between the ages of 18-65. Members who were male (n = 1092), intersex (n = 1), did not provide biological sex (n = 54), retired (n = 35), medically released (n = 49), or did not provide CAF employment status (n = 22), were excluded from this study. Therefore, the final n = 748 was used for this analysis. This study was approved by the local Research Ethics Board (H-04-19-3442) and the procedures were performed in accordance with the Declaration of Helsinki.

The minimum required sample size for the larger project was estimated using two strategies: i) representation of the overall CAF population and ii) previously reported odds ratios from studies comparing MSKi rates from females vs. males in the military context. For the present study, we used the minimum sample size derived from the first strategy. The estimated number of CAF members (i.e., Regular Forces and Reserves) is 103,873 with approximately 16% being female (Jackson, 2020). Considering the estimated prevalence of repetitive strain injuries (RSI) (~ 35%) and acute injuries (~ 19.8%) reported in female CAF members (Guerin, 2020), maximum error of ± 5%, and a design effect of 1.5 (accounting for the nature of recruitment and study design), the minimal sample size was n = 508.

Variables

Parity status and pregnancy-related complications (e.g., postpartum depression, miscarriage, stillborn, or traumatic birth [use of vacuum or forceps, or episiotomy required]) were used as the independent variable, MSKi rates (RSI and acute injuries) and MSKi related outcomes (e.g., impact on daily activities, mental health status) were analyzed as dependent variables.

Appendix 1 further describes all the independent variables, covariates, and outcomes used in the analysis. The original categories for response, categories, and references for analysis are also presented in the same table.

Statistical Analysis

All analyses were conducted with IBM SPSS Statistics version 27 (SPSS Inc., Chicago, Ill, USA) and significance was set at $p < 0.05$. Data were presented descriptively as absolute (n) and relative (%) frequencies, as well as median and range (minimum and maximum). For continuous variables, data normality was checked using the Shapiro-Wilk test. Comparisons between groups (Parous vs. Nulliparous) were made using Mann-Whitney U test, according to the results of the normality test (non-normality-distributed data). Chi-square tests or Fisher's Exact tests (i.e., when the assumption of having < 20% of the cells, with an expected count of less than 5, was not met) were used to test the bivariate associations (i.e., 2x2) between the independent variables (parity and pregnancy related complication) and the outcomes (MSKi and health outcomes). Independent variables not significantly associated with the outcomes ($p \geq 0.05$) were not moved to the logistic regression analysis. For the significant bivariate associations, binary logistic regression models were generated and include the adjusted odds ratio (95% confidence intervals [CI] and p-values) using age, rank, military environment, and current body mass index (BMI) classification as covariates, unless otherwise indicated (e.g., if they have not met a test assumption). The following assumptions were confirmed for the binary logistic regressions: i) sufficiently large sample size (i.e., at least 10 observations with the least frequent outcome for each independent variable); ii) multicollinearity for independent variables and covariates included in the model; iii) linearity of the logit for the continuous covariate included (i.e., age); iv) goodness of fit (i.e., Hosmer-Lemeshow test).

RESULTS

The participant demographics (n = 748) for this study are outlined in Table 1.

Table 1. Participant Characteristics

Category	Parous (n = 313)	Nulliparous (n = 435)
Age (years)	40.0 ± 6.8	35.6 ± 9.5
BMI (kg/m^2)	27.4 ± 5.2	26.3 ± 4.9
Year of Enrollment	2001.9 ± 7.4	2009.2 ± 8.5
Rank:		
NCM (%)	50.5	59.2
Officers (%)	49.5	40.8
Military Element:		
Canadian Army (%)	40.6	49.7
Royal Canadian Navy (%)	14.3	7.9
Royal Canadian Air Force (%)	45.1	42.4

BMI: Body Mass Index; NCM: Non-Commissioned Members.
Continuous variables presented as mean and standard deviation. Shapiro-Wilk Normality Test < 0.001 for all continuous variables.

Repetitive Strain Injuries

Parous members reported more RSI overall compared to the nulliparous group (80.9% v. 69.9%, p = 0.002). A comparison of RSI prevalence, stratified by body region, is displayed in Figure 1. When adjusted for age, BMI, military environment, and rank, parous females were more likely to report an RSI (aOR: 1.573, CI: 1.025; 2.415, p = 0.038) compared to the nulliparous group. When stratified by body region, parous females were more likely to report an RSI of the wrist (aOR:1.628, CI: 1.09; 2.430, p = 0.017), and foot (aOR: 1.742, CI: 1.199; 2.530, p = 0.004).

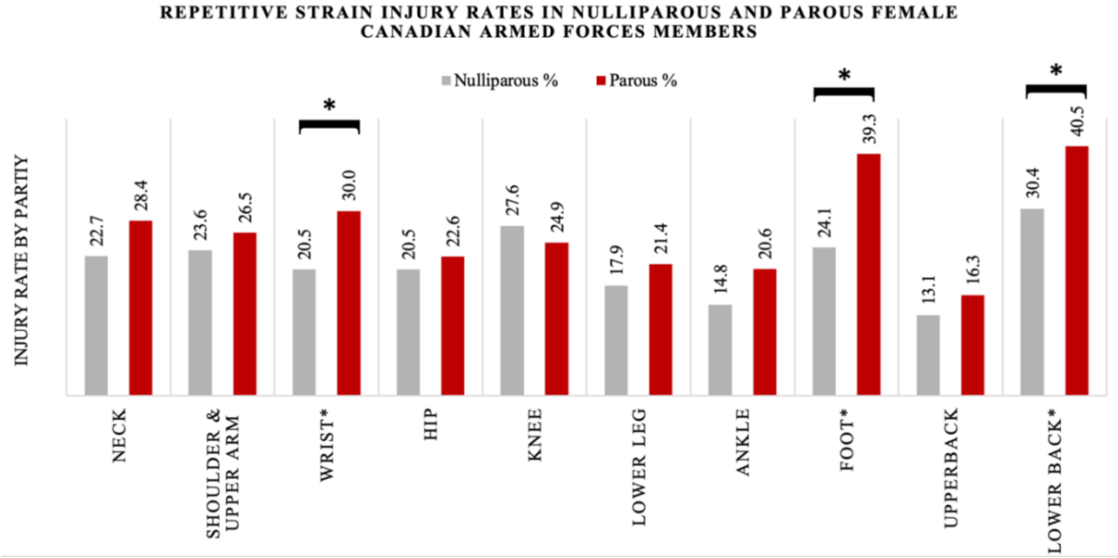

Figure 1. Rates of repetitive strain injuries reported by nulliparous (n = 352), and parous (n = 256) female Canadian Armed Forces members stratified by body region (total n = 608). *Significant difference Chi-square $p \leq 0.05$.

Repetitive Strain Injury Related Outcomes

Of the participants who sustained RSI (n = 453), 34.5% (35.1% nulliparous vs. 33.8% parous, p = 0.771) had an impacted career progression or length, and 75.1% (74.5% nulliparous vs. 75.9% parous, p = 0.831) formally reported their RSI to a medical health professional. While RSI interference with work duties was observed at similar rates between parous and nulliparous (59.6% nulliparous vs. 58.2% parous; p = 0.760), the parous group reported a higher impact on daily activities (76.2% nulliparous vs. 88.4% parous; $p \leq 0.001$).

Acute Injuries

Acute injuries were reported by 59.2% of participants (58.0% nulliparous vs. 60.7% parous; p = 0.512) and no significant differences were observed when stratifying by body region or acute injury type. The most common body areas affected by acute injury were the ankle (28.7%), lower back (23.5%), and knee (20.8%). Sprains and strains were the most reported acute injury type (35.9%), followed by broken bones (13.1%), scrapes and bruises (11.6%), and concussions (9.6%).

Acute Injury-Related Outcomes

Of the participants who sustained an acute injury (n = 354), 38.5% (39.7% nulliparous vs. 36.9% parous, p = 0.597) felt the injury impacted career progression or length, and 90.2% (87.7% nulliparous vs. 93.2% parous, p = 0.204) formally reported acute injuries to a medical health professional. No difference in daily activities (56.8% nulliparous vs. 58.0% parous; p = 0.820) or work duties (55.0% nulliparous vs. 45.0% parous; p = 0.064) being negatively impacted by acute injury were observed.

Pregnancy-Related Complications

Seventy-two out of 313 participants with a history of childbirth did not respond to questions pertaining to pregnancy-related complications. The following pregnancy-related complications were reported (n = 241): previous miscarriage (26.6%), preterm birth (9.1%), gestational diabetes mellitus (7.1%), preeclampsia (7.5%), gestational hypertension (3.7%), postpartum depression (22.4%), and traumatic birth (28.6%). Significant findings comparing the pregnancy-related complications with MSKi, and health-related outcomes identified using Chi-square were carried forward for bivariate logistic regression analysis presented in Table 2.

Table 2. Bivariate logistic regression analysis of injuries in Canadian Armed Forces members who have given birth and experienced pregnancy related complications.

Outcome	**Adjusted Odds Ratio**	**Lower Limit**	**Upper Limit**	**Significance Level**
Overall Acute Injury				
Miscarriage *	1.950	1.017	3.740	0.044
RSI Lower Back				
Miscarriage *	2.223	1.207	4.097	0.010
Postpartum Depression	2.181	1.160	4.100	0.015
RSI Head, Eyes, Ears				
Postpartum Depression *	3.434	1.550	7.607	0.002
RSI Hip				
Postpartum Depression *	2.467	1.231	4.944	0.011
Good/Very Good/Excellent Mental Health				
Miscarriage *	0.289	0.143	0.583	<0.001
Preterm Birth *	0.236	0.084	0.662	0.006
Postpartum Depression *	0.282	0.142	0.562	<0.001
RSI Wrist				
Preterm Birth	2.510	0.984	6.397	0.053
Acute Injury Hip				
Postpartum Depression *	3.911	1.491	10.257	0.006

Covariates included in all analyses are age, body mass index, rank, and military environment. Reference group for all analysis was “No”, except Good/Very Good/Excellent Mental Health was compared to Poor/Fair. * Significant difference $p \leq 0.05$.

Physical Training Through Pregnancy and the Post-Partum

Descriptive analysis of questions pertaining to physical training provided during pregnancy and postpartum is illustrated in Figure 2.

Physical Training Participation	Pregnancy	Postpartum (6-12 months)
Specialized PT support	6.7%	7.6%
Participated in work- related PT with no modification	49.3%	
Stopped all PT	27.7%	4.7%
Self-directed modifications to PT	42.4%	30.2%
Modified PT due to policy	20.3%	2.8%
Completed all phases of scheduled PT program without modification	5.1%	--

Figure 2. Physical training participation, modification, and support through pregnancy and the postpartum period of female CAF members. PT = Physical training.

DISCUSSION

This present study illustrates that experiencing childbirth and pregnancy-related complications are associated with greater prevalence of injuries in CAF members. Firstly, participants with a history of childbirth were more likely to have RSI overall, compared to their nulliparous peers. Moreover, the parous group was more likely to have RSI at the foot or wrist. Secondly, female CAF members who have given birth and experienced previous miscarriage, postpartum depression, or preterm birth were more likely to report select injuries. Those who experienced postpartum depression were 3.9 times more likely to have an acute hip injury, compared to parous members who did not. RSI in the lower back, head/eyes/ears, or hip were also more likely to be reported by those who had postpartum depression.

Parity Status

The higher rate of wrist RSI reported by the parous group was expected considering carpal tunnel syndrome, an RSI involving the wrist, has been associated with pregnancy (Padua et al., 2010). A literature review performed by Padua *et al.* (2010) found that pregnancy-related carpal tunnel syndrome affected approximately 17% of research participants. While 30% of our parous sample reported wrist RSI, specific diagnosis was not accounted for. Padua *et al.* (2010) also noted that most cases of pregnancy-related carpal tunnel syndrome appear to resolve spontaneously within one to three years. Research exploring wrist injury in parous CAF females should consider known risk factors for pregnancy-related carpal tunnel syndrome (i.e., obesity, BMI, gestational weight gain, and relaxin) (Kang et al., 2017, Wright et al., 2014).

Other injuries associated with pregnancy are not prominent in the literature. However, pain at specific body regions throughout pregnancy, such as plantar pain, is fairly well documented (Anselmo et al., 2017). There are a number of changes identified in the foot during pregnancy (i.e., length, width, volume), and altered plantar pressure distribution during gait has been observed (Gimunová et al., 2020, Vico Pardo et al., 2018, Wetz et al., 2006, Anselmo et al., 2017, Christopher et al., 2022). The changes in the foot can persist after childbirth and are attributed to increases in body mass and endocrine system responses to pregnancy (Vico Pardo et al., 2018, Segal et al., 2013). While it is unclear if these pregnancy related changes contribute to injury risk at the foot in female CAF members, considerations for these members are recommended when returning from maternity leave. Specifically, scheduled fitting of new personal protective equipment (i.e. footwear, uniform) after pregnancy should be prioritized to ensure the member is adequately protected when returning to duty. Physical training programs for CAF members who have given birth should be created with the understanding the wrist and feet may be more susceptible to injury. Further, practitioners should assess gait after pregnancy to determine if the new movement patterns are potentially problematic.

Pregnancy Related Complications

Our review of the literature did not uncover specific research examining postpartum depression and MSKi, though associations with lumbopelvic pain have been documented previously (Gutke et al., 2007). In a cohort study conducted by Gutke *et al.* (2007), depressive symptoms were three times more likely in participants with lumbopelvic pain at three months postpartum (Gutke et al., 2007). To note, the prevalence of postpartum depressive symptoms (Edinburgh Postnatal Depression Scale screening cut-off >10) in Gutke *et al.* (2007) was 8% compared to postpartum depression diagnosis of 26.6% in this present study (Gutke et al., 2007). Disparities in depression rates between our study and Gutke *et al.* (2007) could be attributed to our data being collected via self-report questionnaire and our population of focus (military), compared to depression assessed in clinic and general Scandinavian population (Gutke et al., 2007). Further, this present study did not include pain, pregnancy, or postpartum specific MSKi questions, only injuries sustained while serving in the CAF were examined. While 43% of medical releases by women from the CAF are MSKi related, 45% are attributed to mental health (Dursun, 2020, Serré, 2019). Additional screening and psychological support should be incorporated into the postpartum care for CAF members as they may be at additional risk for MSKi.

Our findings indicate associations between miscarriage and some MSKi. It is possible that behaviour and psychological factors are contributing to the relationship between miscarriage and these injuries. Factors such as smoking, lifestyle, and medical conditions increase risk of both outcomes (Sammito et al., 2021, Qu et al., 2017). Another factor to consider is vitamin D deficiency. Females diagnosed with vitamin D deficiency (<50 nmol/L) are at an increased risk of miscarriage compared to females who are vitamin D replete (>75nmol/L) (Tamblyn et al., 2022). Additionally, vitamin D deficiency is correlated with increased bone fracture risk and the pathophysiology of depression (Vellekkatt and Menon, 2019, Jakobsen et al., 2021). To note, in this present study, participants who had experienced miscarriage were more likely to report lower levels of mental health. Stress and depressive symptoms caused by either miscarriage or MSKi may be contributing to the correlation (Wong et al., 2021, Franche et al., 2009, Farren et al., 2020, Qu et al., 2017, Rangel et al., 2021). Specifically, depression is associated with less efficient recovery and greater disability in people with lower back pain and increased complications in patients with traumatic MSKi (Tamblyn et al., 2022, Vellekkatt and Menon, 2019, Jakobsen et al., 2021).

Additional Considerations and Limitations

Our findings associating pregnancy related complications and parity status with MSKi demonstrate the need for collaboration between practitioners when supporting the female CAF member. The medical conditions included in this study often require specialized care that can be supported by physical training. Evidence-based physical training programs are effective at decreasing RSI risk in combat trained females and may be an important method of protecting a body that has undergone childbirth from MSKi (Knapik et al., 2003). The rates of CAF members not receiving specialized training guidance during pregnancy (93.4%) and postpartum (92.4%) indicated by our analysis of physical training participation (Figure 2), and minimal support for exercise or program modifications, initiatives in this area are strongly recommended.

The cross-sectional, retrospective study design of this present study limits the level of evidence and application of our findings. As data pertaining to pregnancy as a risk factor for MSKi are lacking, this questionnaire follows the recommended injury surveillance methods proposed for both sport and military (Meeuwisse, 1994, Meeuwisse et al., 2007, Bahr and Krosshaug, 2005, Jones et al., 2018). The contributions of childbirth and pregnancy- related complications as possible risk factors of MSKi in the CAF justifies further investigation. Specifically, timing of injuries in relation to pregnancy and the postpartum period, injury types (e.g., carpal tunnel syndrome, diastasis recti), type of delivery (vaginal birth, planned cesarian-section, unplanned cesarian-section), and pain conditions (e.g., pelvic girdle pain, low back pain) should all be examined. It is important to note the prevalence of miscarriage in this study only includes females who currently have biological children, participants who answered 'no' to having children did not receive questions pertaining to pregnancy related complications. While more information is needed before a causal relationship can be established, clinicians may consider our findings in the care of a female CAF member.

CONCLUSION

Parous female CAF members and those who experienced pregnancy-related complications were more likely to experience MSKi while serving. Females who have a history of childbirth were more likely to report RSI at the wrist and foot when compared to the nulliparous group. Postpartum depression, miscarriage, and preterm birth may also be associated with an increased risk of MSKi and poor mental health status. The low rates of CAF members receiving specialized training during pregnancy and postpartum highlights an opportunity for future interventions. Body regions at higher risk of MSKi identified in this study may inform physical training programs created for female CAF members and should be considered in future research. Injury prevention strategies and postpartum support are needed to offset the impact of childbirth on the female CAF member.

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APPENDIX

Appendix 1. Independent variables, covariates, and outcomes.

N	Independent Variable	Original Categories for Response	Categories and Reference for Analysis
1	Parity (only included female respondents)	1) Discrete variable (number of biological children)	1) 0 (reference) 2) 1+
N	**Covariate**	**Original Categories for Response**	**Categories and Reference for Analysis**
1	Age	Continuous variable (years)	Continuous variable (years)
2	CAF rank	1) Junior NCM - Pte/OS/AB/Avr 2) Junior NCM - Cpl/LS 3) Junior NCM - MCpl/MS 4) Senior NCM - Sgt/PO2 5) Senior NCM - WO/PO1 6) Senior NCM - MWO/CPO2 7) Senior NCM - CWO/CPO1 8) Junior Officer - OCdt/NCdt - 2Lt/A/SLt 9) Junior Officer - Lt/SLt 10) Junior Officer - Capt/Lt(N) 11) Senior Officer – Maj/LCdr 12) Senior Officer - LCol/Cdr 13) Senior Officer - Col/Capt(N) - General Flag	1) NCMs 2) Officers (reference)
3	Military Environment	1) Army 2) Royal Canadian Navy 3) Royal Canadian Airforce	1) Army (Reference) 2) Royal Canadian Navy 3) Royal Canadian Airforce
4	Current BMI classification	1) Continuous variable (combination of current weight and height (kg/m^2))	1) Underweight and normal weight (reference) 2) Overweight 3) Obese

N	Outcomes	Original Categories for Response	Categories and Reference for Analysis
1	Experienced anything medically related during the fitness evaluation test that required the test to be stopped, postponed, or cancelled	1) Yes 2) No	1) Yes (Reference) 2) No
N	Outcomes	Original Categories for Response	Categories and Reference for Analysis
Repetitive Strain Injuries			
Now questions on repetitive strain or overuse injuries. By this we mean injuries to muscles, tendons or nerves caused by overuse or repeating the same movement (e.g., ruck marching) over an extended period. For example, carpal tunnel syndrome, tennis elbow, plantar fasciitis, or tendonitis. In case of retired/released members, please indicate the most accurate reply while a serving member.			
1	While serving, did you ever have any injuries that you felt were due to repetitive strain?	1) Yes 2) No	1) Yes (reference) 2) No
What part(s) of the body were most affected by repetitive strain injuries (select all that apply):			
2	Head, Eyes, Ears	1) Yes 2) No	1) Yes 2) No
3	Neck	1) Yes 2) No	1) Yes 2) No
4	Shoulder, Upper arm	1) Yes 2) No	1) Yes 2) No
5	Elbow, Lower arm	1) Yes 2) No	1) Yes 2) No
6	Wrist	1) Yes 2) No	1) Yes 2) No
7	Hand	1) Yes 2) No	1) Yes 2) No
8	Hip	1) Yes 2) No	1) Yes 2) No
9	Thigh	1) Yes 2) No	1) Yes 2) No
10	Knee, Lower leg	1) Yes 2) No	1) Yes 2) No
11	Ankle	1) Yes 2) No	1) Yes 2) No
12	Foot	1) Yes	1) Yes

		2) No	2) No
13	Toes	1) Yes 2) No	1) Yes 2) No
14	Upper back/spine	1) Yes 2) No	1) Yes 2) No
15	Lower back/spine	1) Yes 2) No	1) Yes 2) No
16	Chest	1) Yes 2) No	1) Yes 2) No
17	Abdomen or pelvis	1) Yes 2) No	1) Yes 2) No
18	Do you feel any of your repetitive strain injuries impacted your career progression or length?	1) Yes 2) No	1) Yes (reference) 2) No
19	How often, over your career, did repetitive strain injuries interfere with your daily activities?	1) Never 2) Rarely 3) Sometimes 4) Most of the time 5) All of the time	1) Never and rarely 2) Sometimes, most of the time, all of the time
20	How often, over your career, did repetitive strain injuries interfere with your occupation performance?	1) Never 2) Rarely 3) Sometimes 4) Most of the time 5) All of the time	1) Never and rarely 2) Sometimes, most of the time, and all of the time
Acute Injuries			
Now some questions about serious acute injuries. Think about physical injuries, likely caused by a significant level of exertion or single incident of trauma, which were serious enough to require at least 24 hours off work after it to recover from. For example, a broken bone, a sprain. In case of retired/released members, please indicate the most accurate reply while a serving member.			
21	While serving, did you ever have any acute	1) Yes 2) No	1) Yes 2) No

	injuries that were serious enough to take at least 24 hours off from work?		
What part(s) of the body were most affected by acute injuries that were serious enough to take at least 24 hours off from work (select all that apply):			
22	Head, Eyes, Ears	1) Yes 2) No	1) Yes 2) No
23	Neck	1) Yes 2) No	1) Yes 2) No
24	Shoulder, Upper arm	1) Yes 2) No	1) Yes 2) No
25	Elbow, Lower arm	1) Yes 2) No	1) Yes 2) No
26	Wrist	1) Yes 2) No	1) Yes 2) No
27	Hand	1) Yes 2) No	1) Yes 2) No
28	Breast	1) Yes 2) No	Not included.
29	Hip	1) Yes 2) No	1) Yes 2) No
30	Thigh	1) Yes 2) No	1) Yes 2) No
31	Knee, Lower leg	1) Yes 2) No	1) Yes 2) No
32	Ankle, Foot	1) Yes 2) No	1) Yes 2) No
33	Upper back/spine	1) Yes 2) No	1) Yes 2) No
34	Lower back/spine	1) Yes 2) No	1) Yes 2) No
35	Chest	1) Yes 2) No	1) Yes 2) No
36	Abdomen	1) Yes 2) No	1) Yes 2) No
37	Pelvis	1) Yes 2) No	1) Yes 2) No
38	Do you feel that any of your acute injuries impacted your career progression or length?	1) Yes 2) No	1) Yes 2) No
39	How often, over your career, did acute injuries that were serious enough	1) Never 2) Rarely 3) Sometimes 4) Most of the time 5) All of the time	1) Never and rarely 2) Sometimes, most of the time, all of the time

	to take off at least 24 hours from work interfere with your daily activities?		
40	How often, over your career, did acute injuries that were serious enough to take off at least 24 hours from work interfere with your occupation performance?	1) Never 2) Rarely 3) Sometimes 4) Most of the time 5) All of the time	1) Never and rarely 2) Sometimes, most of the time, all of the time
Reproductive health			
41	During any of your pregnancies while serving, did you have any of the following pregnancy-related complications?	1) Miscarriage 2) Stillbirth 3) Preterm birth 4) GDM 5) Preeclampsia 6) IUGR 7) Gestational hypertension 8) Postpartum depression 9) Traumatic birth (e.g., use of vacuum or forceps, or episiotomy required	1) Miscarriage 2) Stillbirth 3) Preterm birth 4) GDM 5) Preeclampsia 6) IUGR 7) Gestational hypertension 8) Postpartum depression 9) Traumatic birth (e.g., use of vacuum or forceps, or episiotomy required

CAF = Canadian Armed Forces, BMI = body mass index, NCM = non-commissioned members, RSI = repetitive strain injuries, GDM = gestational diabetes mellitus, IUGR = intrauterine growth restriction.

CHAPTER 3 PREAMBLE

The findings in Chapter 2 indicate that CAF members with a history of childbirth experience more RSI than their nulliparous counterparts. As physical fitness declines throughout pregnancy and is related to MSKi risk, it is possible that fitness is playing a role in this disparity. This study examines flexibility, muscular endurance, power, and strength, in addition to aerobic capacity in Purple Trade members of the CAF. The Purple Trades military occupation specialties provide support universally (e.g., health care, administration, military police, etc.). Individuals employed in these trades may be posted to any element (Royal Canadian Air Force, Canadian Army, Royal Canadian Navy, or Canadian Special Operations Forces Command) and work in a variety of environments both at home and in theatre. Thus, the physical demands placed on these members can change dramatically between postings. As over half of the females serving in the CAF are employed in the Purple Trades category, this population was selected to be included in the subsequent two studies.

Chapter 3

Parity Status and Injury as Predictors of Physical Fitness in Military Personnel

Study title: Are a history of childbirth or musculoskeletal injury related to physical fitness in female members of the Canadian Armed Forces

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Components of this chapter have been presented as an abstract:
"*Effects of parity status on physical fitness of Purple Trade members of the Canadian Armed Forces with repetitive strain injury history*"
Canadian Society for Exercise Physiology Conference, Fredericton, Canada 2022

This chapter is formatted for *Applied Physiology, Nutrition, and Metabolism*

Contributions:
CME, DFdS, SCS, JP, KS, and KBA created the questionnaire used for this study. Participant communication and scheduling was performed by CME. Study site coordination and logistics were performed by CME. Equipment procurement was conducted by KS, DFdS, and CME. Data collection was performed by CME, EM, DFdS, JP, SCS, and KS. Data cleaning was performed by CME, SCS, DFsS, and JP. Data analysis for this study was performed by CME. DFdS and KBA lead the project in which this study is included, with funding grant was procured by KBA, DFdS, KS. All authors contributed to the design of the study, revised, edited, read, and approved the final version of the manuscript.

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CHAPTER 3 SUMMARY INFOGRAPH

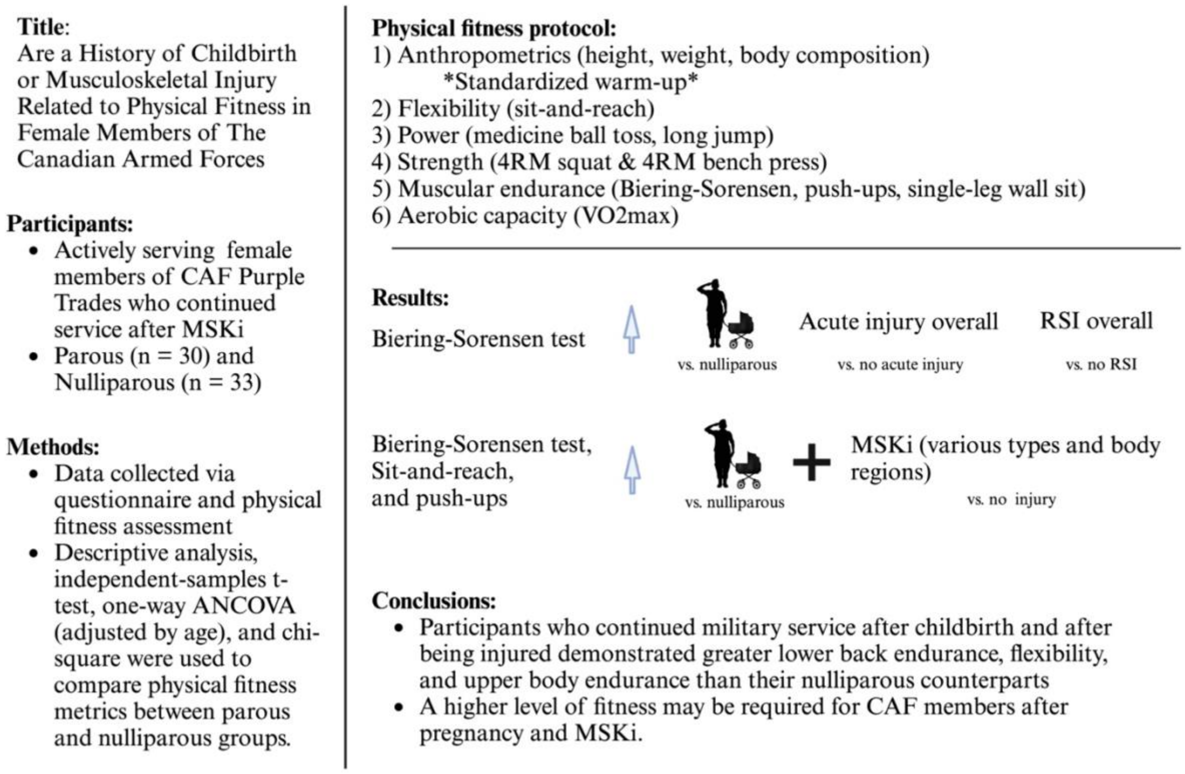

Figure 3.0 Visual summary of *Project 2 "Are a History of Childbirth or Musculoskeletal injury Related to physical Fitness in Female Members of The Canadian Armed Forces?"*. ANCOVA = Analysis of covariance, CAF = Canadian Armed Forces, RSI = repetitive strain injuries, RM = repetition maximum, MSKi = musculoskeletal injuries.

ABSTRACT

Musculoskeletal injuries (MSKi) are among the top reasons for attrition from the Canadian Armed Forces (CAF), with female members being at greater risk. As most female members serving in the CAF are of childbearing age, examination of female reproduction as a risk factor for MSKi is warranted. Demographic and MSKi (self-report) data were collected by online questionnaire (Survey Monkey [San Mateo, CA]) and physical fitness (sit-and-reach test, standing long jump, medicine ball throw, back squat, bench press, Biering-Sorenson test, single-leg wall sit, and VO_{2max}) data were obtained by in-person assessment. Descriptive analysis, independent-samples t-test, one-way ANCOVA (adjusted by age), and chi-square were used to compare physical fitness results between parous (n = 30) and nulliparous (n = 33) groups. A p-value <0.05 was considered significant. Biering-Sorenson performance was superior in participants who had given birth and i) sustained acute injury (p = 0.030), ii) acute injury to the head, neck, and upper back (p = 0.031), iii) repetitive strain injury (RSI) (p = 0.026), or iv) RSI to the lumbopelvic hip complex (p = 0.023). Parous members with history of acute injury to the lower extremity also performed more push-ups (p = 0.025) and back squat (0.033). Participants who continued military service after childbirth and after being injured demonstrated greater lower back endurance, flexibility, and upper body endurance than their nulliparous counterparts. A higher level of fitness may be required for CAF members after pregnancy and MSKi.

INTRODUCTION

Females began serving in the Canadian military in 1885 and in 1965, employment was permanently opened for women and female members.(1) Since then, women have increased their presence in the Canadian Armed Forces (CAF) to approximately 15%.(2) Under Strong, Secure, Engaged: Canada's Defence Policy, a goal was set to increase the representation of women in the CAF to 25.1% by 2026.(2) Musculoskeletal injuries (MSKi) are among the top reasons for overall attrition from the CAF, with female members more likely to be medically released due to MSKi compared to male peers.(3, 4) Explaining how MSKi impact active-duty female CAF members is challenging as this population is underrepresented in the literature. Further complicating the interpretation of findings pertaining to sex-disparities in MSKi is the recent distinction of acute (AI) and repetitive strain injuries (RSI).(5) Compared to their male colleagues, female CAF members are more likely to sustain an RSI.(6) Proposed factors contributing to the increased risk in females compared to males are muscle activation patterns, anatomical structure, hormone differences, including those associated with the menstrual cycle, and other events associated with female reproduction (e.g., pregnancy and the postpartum).(7)

Given that the majority of female CAF members are of childbearing age, examination of female reproduction as a risk factor for MSKi is warranted.(8, 9) Pregnancy is associated with anatomical, biomechanical, and physiological changes, some of which persist beyond the postpartum period.(10-14) These changes can result in altered gait kinematics, decreased muscle activation, increased joint laxity, and affect the cardiorespiratory system, all of which can impact physical exertion and exercise tolerance during pregnancy and postpartum.(15-17) Physical fitness deficits in United States servicewomen postpartum have been noted to impede their ability to achieve mandatory physical employment standards.(18) It is possible that these fitness deficits contribute to servicewomen being at increased risk of sustaining an injury in the first year postpartum, and parous female CAF members sustaining more injuries to the pelvis during the annual physical fitness test (compared to nulliparous peers).(19, 20) Additionally, female CAF members with a history of childbirth are also more likely to report sustaining an RSI than their nulliparous counterparts.(21) Injury after returning from maternity leave may be, in part, why female CAF members are more likely to be medically released due to MSKi.(4) Conversely, it is unclear what attributes exist in female CAF members who have given birth and sustained an MSKi, but continued military service. The most common events driving female members to release from the CAF are i) injury and ii) pregnancy.(22) Given the adverse impact injury and pregnancy can have on fitness, an investigation into physical performance of nulliparous and parous CAF members who have experienced an MSKi is justified. As physical demands vary between military occupation specialty (MOS), which might impact the decision to release, occupation related variables need to be considered for this analysis.

The CAF is comprised of three elements: 1) The Royal Canadian Air Force (RCAF), 2) The Royal Canadian Navy (RCN), and 3) The Canadian Army (Army). The CAF MOS categories providing support universally (e.g., health care, administration, military police, etc.), fall into a fourth category termed ‘Purple Trade’. Members of these trades may work in all three elements during their careers and face unique physical demands. Over half of all female CAF members are employed in the Purple Trade category.(22) A recent study conducted by the Women in Ground Close Combat Research Programme of the United Kingdom suggested female service personnel are unprepared for the demands of full active duty in the first year postpartum and are more vulnerable to illness and injury.(19) The long-term effects of bearing children on MSKi risk are not well described in the literature.

Investigating the physical fitness attributes of CAF Purple Trades members who continue to serve after both MSKi and childbirth could inform interventions to improve retention. Thus, this study explores the impact of parity status on muscular power, strength, endurance, flexibility, and aerobic capacity of female Purple Trade members who continued service after sustaining MSKi. We anticipate the nulliparous members will exhibit superior physical fitness than the parous group.

MATERIALS AND METHODS

This present study was a planned sub analysis of a larger project titled *A multi-stage approach to addressing sex-disparities in musculoskeletal injuries in military members.* Occupation, demographic, and MSKi (self-report) data collection were conducted via online questionnaire (Survey Monkey [San Mateo, CA]) and physical fitness data were collected during an in-person assessment session from October 2021 to January 2022. The social networks of the research team and stakeholders, as well as media platforms, and snowball sampling, were used to recruit participants. The inclusion criteria for the study were being: i) female sex, ii) between the ages of 18 and 55 years, iii) an active duty member of CAF, iv) cleared to engage in maximal exercise (based on the Health Appraisal Questionnaire), v) having sustained a musculoskeletal injury while serving in the CAF (self-report), and vi) providing informed consent to participate (in English or French). A total of 110 participants were recruited; however, 15 did not attend the assessment session and 5 participants had their sessions cancelled due to COVID-19 related issues. Of the 90 participants who completed the in-person protocol, 66 were from Purple Trades. Further, 3 participants were excluded from this analysis as their year of enrollment was less than 2 years prior to testing. Of the 63 participants included, 33 were nulliparous, and 30 had carried at least one pregnancy to 20 weeks of gestation or more. All procedures of the present study have been reviewed and approved by the University Research Ethics Board (H-11-20-6180) and were conducted in accordance with the Declaration of Helsinki.

Participant body weight and composition data was collected using the InBody® (USA) bioelectrical impedance analyzer (BIA). Physical testing assessed muscular power, strength, endurance, flexibly, and aerobic capacity in nulliparous (have not given birth) and parous (have given birth) female members from the CAF who have sustained MSKi and returned to active duty. The tests included in this protocol were: sit-and-reach test, standing long jump, medicine ball explosive power test, four repetition maximum back-squat and bench press, Biering-Sorenson test, single-leg wall sit, and a maximal incremental exercise test to measure VO_{2max}.(23) The following MSKi definitions were provided to participants when self-reporting injury:

i) *"Repetitive strain means injuries to muscles, tendons or nerves caused by overuse or repeating the same movement (e.g., ruck marching) over an extended period."* and

ii) *"Acute injuries… physical injuries, likely caused by a significant level of exertion or single incident of trauma, which were serious enough to require at least 24 hours off work after it to recover from."*

A detailed list of outcomes, variables, and data collection methods used for this protocol is included in Appendix 1.

The minimum required sample size for this project was estimated based on Bagwell *et al.*, 2020 who compared the gait mechanics of 23 females through pregnancy and postpartum with 23 nulliparous controls.(10) Accepting a maximum error of ± 5%, and a desired power of 80%, the minimal sample size for each group was n = 36.

Statistical Analysis

Normality (Shapiro-Wilks) and variance (Levene's test) assumptions were checked. T-tests were used to compare the means of continuous descriptive variables. T-tests are considered robust enough for non-normal data.(24) The bivariate associations for 2x2 tables were analyzed using a Chi-square test or Fisher's Exact test when the assumption of having <20% of the cells, with an expected count of less than 5, was not met. Numbers and percentages were used to describe categorical variables. Means and standard deviations were used to describe continuous variables. Welch's t-test was used to compare years of service as it did not meet the assumption of equality of variance. One-way analysis of covariance (ANCOVA) was used to analyze outcomes related to physical fitness.(25) After checking for collinearity using a fit line plot, age was the only covariate included in the ANCOVA. Bonferroni correction was applied, and effect size was reported by partial Eta squared. A p-value <0.05 was considered significant.

RESULTS

A comparison of participant demographics, split by parity status, are presented in Table 1.

Table 1. Participant demographics.

Variable	Nulliparous		Parous		p-value
	N		N		
Age (years), mean ± SD	33	32.2 ± 7.5	30	37.5 ± 6.1	0.003*
Height (m), mean ± SD	33	1.64 ± 0.06	30	1.65 ± 0.06	0.939
Body weight (kg), mean ± SD	33	71.4 ± 13.5	30	67.7 ± 11.1	0.240
BMI (kg/m^2), mean ± SD	33	26.4 ± 4.5	30	25.1 ± 4.3	0.234
Years serving, mean ± SD	33	8.5 ± 6.3	30	12.8 ± 7.3	0.016*
Body fat (%), mean ± SD	33	30.9 ± 7.4	30	28.1 ± 8.2	0.152
Skeletal muscle mass (kg), mean ± SD	33	27.3 ± 4.0	30	26.6 ± 2.9	0.445
Rank					
NCM (n, %)	18	54.5	21	70.0	0.207
Officers (n, %)	15	45.5	9	30.0	
Use of hormones for birth control					
Yes (n, %)	13	39.4	7	23.3	0.171
No (n, %)	20	60.6	23	76.7	
Menstrual cycle periodicity					
Regular (n, %)	21	63.6	16	53.3	0.407
Irregular (n, %)	12	36.4	14	46.7	
Menopause					
Yes (n, %)	0	0.0	2	6.7	0.223
Sit-and-reach (cm)	33	34.3 ± 7.2	30	36.6 ± 6.2	0.196
Long jump (cm)	33	159.9 ± 28.0	30	157.7 ± 23.1	0.742
Medicine ball throw (cm)	33	260.8 ± 65.4	30	272.7 ± 32.5	0.372
4RM back squat (lbs.)	32	153.1 ± 42.3	28	148.9 ± 40.5	0.697
4RM bench press (lbs.)	32	86.6 ± 25.9	30	81.7 ± 18.8	0.401
Biering-Sorenson (sec)	33	110.3 ± 47.8	30	146.8 ± 58.2	0.008*
Left leg wall sit (sec)	33	38.3 ± 24.5	30	38.9 ± 27.8	0.922
Right leg wall sit (sec)	33	40.2 ± 20.3	30	44.3 ± 30.5	0.532
Push-ups (reps)	33	16.3 ± 9.9	30	18.8 ± 10.4	0.333
VO_{2max} (mL/kg/min)	29	41.6 ± 6.9	26	44.0 ± 9.6	0.293

T-tests were used to compare means of continuous descriptive variables. Bivariate associations for 2x2 tables were analyzed using a Chi-square test or Fisher's Exact test (2-sided). One-way ANOVA were used for physical fitness test results (means ± standard deviation). BMI – Body Mass Index; NCM – Non-Commissioned Members; 4RM – 4 repetition maximum. Irregular menstrual cycle periocidy = Never regular, irregular for few months, periods stopped while serving and never had a period. *Significant difference p-value <0.05.

AI were reported by 63.6% of the nulliparous group and 73.3% of the parous group ($p = 0.409$). The effect of parity status on participants with the same acute injury history on physical fitness test performance are outlined in Table 2. No differences were observed in aerobic capacity, muscular power, upper body strength, or flexibility.

Table 2. Significant differences in physical fitness when considering acute injury history and parity status.

Acute Injury	Fitness Metric	Nulliparous	Parous	F	Significance	Partial Eta Square
Overall	Biering-Sorenson (seconds)	n = 21, 103.6 ± 46.6	n = 22, 143.6 ± 61.6	5.037	0.030*	0.112
Head, Neck, UB Complex	Biering-Sorenson (seconds)	n = 5, 67.3 ± 36.2	n = 9, 131.4 ± 53.7	6.119	0.031*	0.357
Lower Extremity	Push-ups (reps)	n = 15, 12.6 ± 7.7	n = 14, 20.1 ± 9.0	5.670	0.025*	0.179
	4RM back squat (lbs.)	n = 14, 152.1 ± 41.6	n = 13, 171.2 ± 32.2	5.118	0.033*	0.176
Scrapes, Bruises, Blisters	Biering-Sorenson (seconds)	n = 10, 90.7 ± 35.5	n = 7, 179.6 ± 87.3	7.106	0.018*	0.337
	Push-ups (reps)	n = 10, 9.4 ± 7.3	n = 7, 21.7 ± 13.1	5.134	0.040*	0.268
	4RM back squat relative to bodyweight (%)	n = 10, 86.2 ± 30.8	n = 6, 112.8 ± 24.6	5.266	0.039*	0.288
Sprain and Strain	Biering-Sorenson (seconds)	n = 15, 100.2 ± 45.1	n = 16, 134.4 ± 43.0	4.545	0.042*	0.140
	4RM back squat relative to bodyweight (%)	n = 15, 99.0 ± 28.9	n = 14, 113.9 ± 25.4	7.620	0.010*	0.227
Fracture	4RM back squat (lbs.)	n = 11, 137.7 ± 28.3	n = 2, 195.0 ± 42.4	5.509	0.041*	0.355
	4RM back squat relative to bodyweight (%)	n = 11, 84.3 ± 16.9	n = 2, 129.0 ± 38.2	8.355	0.016*	0.455

Physical fitness test results of nulliparous and parous participants were compared using one-way ANCOVA (adjusted by age and Bonferroni correction applied). Note that only participants with a history of the injury of interest (e.g., Acute injury at the lower extremity) were included in that respective analysis. UB = upper back; 4RM = 4 repetition maximum. *Significant difference p-value <0.05.

RSI was reported by 81.8% of the nulliparous group and 80.0% of the parous group (p = 0.854). The effect of parity status, when participants were matched with the same RSI history, on physical fitness test performance are outlined in Table 3. No differences were observed in aerobic capacity, muscular power, or muscular strength.

Table 3. Significant differences in physical fitness test scores (mean ± SD) when considering repetitive strain injury history and parity status.

Repetitive Strain Injury	Fitness Metric	Nulliparous (n = 33)	Parous (n = 30)	F	Significance	Partial Eta squared
Overall	Biering-Sorenson (seconds)	n = 27, 108.0 ± 46.1	n = 24, 146.7 ± 63.9	5.292	0.026*	0.101
Head, Neck, UB Complex	Flexibility- sit and reach test (cm)	n = 14, 31.9 ± 8.4	n = 11, 38.8 ± 5.0	5.712	0.026*	0.214
	Right leg wall-sit (seconds)	n = 14, 47.6 ± 25.7	n = 11, 28.3 ± 13.2	4.749	0.041*	0.184
LPHC	Biering-Sorenson (seconds)	n = 19, 105.6 ± 46.1	n = 18, 154.1 ± 63.5	5.766	0.023*	0.142

Physical fitness test results of nulliparous and parous participants were compared using one-way ANCOVA (adjusted by age and Bonferroni correction applied). LPHC = lumbopelvic hip complex, RSI = repetitive strain injury, UB = upper back. *Significant difference p-value <0.05.

DISCUSSION

The present study demonstrates that flexibility, muscular endurance, and muscular strength of CAF members who continued service after MSKi differ based on parity status. Our hypothesis was not supported as the nulliparous group, despite being younger, did not perform better than the parous members.

Low back fitness

Our findings contribute to the existing evidence supporting the inclusion of the Biering-Sorenson test of the isometric endurance of the hip and back extensor muscles in physical fitness assessments of CAF personnel.(26) When stratified by injury history, our results indicate better low back muscular endurance (Biering-Sorenson test) by the parous group for many injury types, including RSI involving the lumbopelvic hip complex. Performance on the Biering – Sorenson has previously been shown to predict injury in CAF members.(26) Interestingly, RSI at the low back are among the most prevalent MSKi in female CAF members, and impact those who have given birth at a higher rate.(6, 20, 21) Based on these data, parous CAF members would be expected to display poorer performance on the low back endurance test as they sustain more injuries. However, we did not confirm this finding in our sample. It is possible that female members with poor low back endurance may be releasing from military service after childbirth. Another possibility is that participants who have been pregnant and continue military service after injury might use their low backs more than nulliparous peers, thus exhibiting greater muscular endurance in this body region due to a training response. Suppose higher demands on the low back musculature are contributing to the parous vs. nulliparous performance-disparity. In that case, it may explain why RSI at this body region is higher in CAF members with a history of childbirth. Superior performance on the Biering -Sorenson was also demonstrated by the parous group for the following injuries: overall RSI, overall AI, sprains/strains, scrapes/bruises/blisters, and AI of the head/neck/upper back. Interestingly, participants in our study achieved better scores on the Biering-Sorenson test than the cutoff indicated by Campbell *et al.,* (2022). Over a 12-month follow-up, Campbell *et al.,* (2022) found CAF members who were unable to perform the Biering-Sorenson test longer than 72 seconds, were at an increased risk of MSKi.(26) This difference could be attributed to varying participant demographics. Those included in Campbell *et al.,* (2022) were male (n = 454, 91.9%) and female (n = 40, 8.1%) members working in combat (n = 215, 43.5%) and support roles (n = 279, 56.5%), with only 7.7% (n = 38) of their sample being Officer rank. As Campbell *et al.,* (2022) did not identify if increased risk of MSKi associated with Biering-Sorenson hold time differed between males and females, it is unclear if the superior test performance in our study is due to our sample being female CAF members with a history of MSKi. Other possible explanations for the longer hold time in this present study compared to Campbell *et al.,* (2022): *i)* female CAF members with a history of MSKi have greater low back muscle endurance than active-duty male CAF members, or *ii)* that females who are able to continue service after injury have stronger musculature in this body region. When the Biering-Sorenson test is included in future investigations, a sex comparison would aid in determining if different cutoffs exist for injury risk.

The sit-and-reach test further supported the importance of low back health for parous CAF members. Greater low back and posterior chain flexibility was demonstrated by parous members who sustained an RSI at the head, neck, and/or upper back, compared to nulliparous peers with the same injury (146.7cm ± 63.9 vs. 108.0 ± 46.1, p = 0.026). While changes in joint laxity in the lumbopelvic hip region have been noted postpartum, poor low back strength and flexibility are associated with pregnancy-related low back pain.(27) Part of the inclusion criteria for this present study was being an active duty member and having a valid CAF medical clearance. It is possible that individuals with poor low back endurance and flexibility deemed themselves ineligible based on medical category or current injury status. Ultimately, the considerable stress placed on the structures in the lumbopelvic hip region in pregnancy and childbirth may yield different physical adaptations in response to injury compared to nulliparous female CAF members.

Upper body fitness

In addition to low back muscular endurance, upper body endurance, may also be an important physical fitness indicator for resilience to injury and childbirth. The number of push-ups completed by parous participants who had sustained an AI involving the lower extremity was significantly higher compared to the nulliparous group in the same injury category (20.14 ± 9.0 v 12.6 ± 7.7, $p = 0.025$). Push-up performance on the United States Navy biannual physical fitness assessment generally returns to pre-pregnancy levels within 12-15 months postpartum.(28) As lower extremity injury recovery can take weeks or months, mothers likely adjust their movements or methods of performing tasks to continue caring for children regardless of ideal resting conditions for healing. This adjustment could place an increased physical demand on the upper body, resulting in a training stimulus, as opposed to a CAF member who does not have children and subsequently engages in less physically demanding activities to support recovery.

Lower body fitness

Our findings suggest lower body fitness performance is impacted differently depending on parity status and injury history. Nulliparous CAF members who had sustained an RSI to the head, neck, and/or upper back demonstrated greater unilateral lower body muscular endurance in the right leg, but not the left, compared to the parous group within the same injury category (47.6 seconds ± 25.7 vs. 28.3 seconds ± 13.2, p =0.041). Given the asymmetrical nature of many military tasks, it is possible that the force transfer from the right leg to the upper body plays a role in strain at the head, neck, and upper back or represents compensation to injury at these body regions. When analyzing participants who had sustained acute injuries of the lower extremity, the difference was in favour of the parous group for the 4 repetition back squat compared to those who have not given birth (152.1 ± 41.6 vs. 171.2 ± 32.2, p = 0.033). The back squat exercise places considerable demand on the gluteus maximus and other muscles responsible for lumbopelvic hip stability.(29, 30) Altered muscle activity persisting from pregnancy and lower extremity injury may compound, resulting in members without considerable lower body strength to release from military service due to their injuries.(10) Interestingly, back squat performance for participants with a history of bone fracture was also better in the parous group with an average weight of 195.0lbs ± 42.4 for 4 repetitions compared to 137.7lbs ± 16.9 for the nulliparous group (p = 0.041). Relative back squat : bodyweight scores for the parous group also exceeded those who have not given birth (129.0% ± 38.2 v. 84.3% ± 16.9, p = 0.016). While higher relative strength in the back squat has been associated with fewer injuries sustained in collegiate athletes, this relationship may be less relevant for females who have given birth or those with higher lower body strength are more resilient to injury.(31) This difference could be attributed to BMD decline in the postpartum, which increases the risk of fracture.(32) Our findings identify a knowledge gap regarding the impact of parity status on the effect of strength or resistance training on BMD and fracture risk.

Considerations and Limitations

This analytical cross-sectional study combines physiological testing with a retrospective component (*i.e.,* questionnaire). As health information and MSKi history was collected using a pre-screening questionnaire and not medical records, the self-report aspect may be considered a limitation of this study. Though self-report may increase recall bias, self-report survey as a method for reporting injuries has been validated against medical records of military personnel.(33)

While the minimum sample size estimated from the power calculation based on parity status was surpassed, it was not adequate for all the analyses related to MSKi, thereby limiting the capacity to assess some statistical relationships. Thus, studies with larger sample sizes are recommended. Further, this study was not designed to determine causality, investigation is needed to understand the relationships observed. Additionally, most participants included in this study were from 4th Canadian Division Support Base Petawawa (4 CDSG). Garrison Petawawa is home to both Regular Force and Special Operations Forces with land and air capabilities, in addition to a multitude of other Units that have high deployment tempos. The deployment cycles of these Units place a higher physical fitness demand on members than other bases. For members deploying with the Canadian Army or in specialty trades, additional physical fitness standards must be met to deploy and field exercises are frequent. Common tasks required for both the physical fitness standard and field exercises include loaded march and heavy lifting; both are a known modifiable risk factors for low back injury, stress fracture, and other MSKi in military personnel.(34-36) As the physical fitness requirements are greater for the members posted in Petawawa, the sample used for this study may not represent the whole CAF.

CONCLUSION

Females CAF members assessed in this present study who continue military service after sustaining MSKi and having carried and birthed a child demonstrated superior physical fitness in multiple components compared to their nulliparous peers. Seemingly, injury type and body region impacted influence performance outcomes. It is unclear if physical fitness adaptations to MSKi are influenced by parity status or if performance on the various tests included in this study (e.g., Biering-Sorenson, push-ups, back squat) indicate resiliency to pregnancy in CAF members who have sustained AI or RSI. Regardless, where fitness differences exist, female CAF members who have previously given birth were better than nulliparous members when matched for injury history. While parity status should be considered when developing initiatives aimed at supporting CAF members with a history of MSKi, our data does not support the position that a history of childbirth equates to lower physical fitness in this active-duty CAF population.

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CONFLICT OF INTEREST

The authors do not have conflict of interest(s) to disclose. We declare the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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APPENDIX

Appendix 1. List of outcomes, variables, and data collection methods used in the physical fitness and physiological testing protocol.

N	Outcomes	Variable Type	Data Collection Method
1	Skeletal muscle mass	Continuous variable (kg)	InBody® (USA) bioelectrical impedance analyzer (BIA).
2	Fat mass percent	Continuous variable (%)	
10	Bone mineral density	Continuous variable (g/cm^2)	The UltraScanTM 650 (CyberLogic, Inc., USA) quantitative ultrasound was placed on the forearm for this measurement. The right forearm was measured three times and both the bone mineral density (g/cm^2) and net time delay (NTD) standard deviation was determined. If the NTD standard deviation was >0.05, two additional measures were performed. The three closest measures of bone mineral density were averaged and used in the analysis.
11	Flexibility	Continuous variable (cm)	The sit-and-reach test, best of 3 attempts.
12	Lower body power	Continuous variable (cm)	Standing long jump test, best of 3 attempts.
13	Upper body power	Continuous variable (cm)	Medicine ball explosive power test, best of 3 attempts.
14	Lower body strength (back squat)	Continuous variable (test weight / body weight)	Four repetition maximum (RM) were performed in the back squat, 4 attempts with 3-5min interval between them.
15	Upper body strength (bench press)	Continuous variable (test weight / body weight)	Four repetition maximum (RM) were performed in the bench press, 4 attempts with 3-5min interval between them.
16	Lower back endurance (Biering-Sorenson test)	Continuous variable (seconds)	The Biering-Sorenson test (maximum time to exhaustion)
17	Lower body endurance	Continuous variable (seconds)	The single leg wall sit (maximum time in each leg) with 1-minute rest interval between legs
18	Lower body endurance	Continuous variable (seconds)	
19	Lower body endurance asymmetry	Continuous variable (%)	Right to left leg difference was calculated based on the single leg wall sit times for each leg.

20	Upper body endurance	Continuous variable (rep)	Push-up test (maximum number of repetitions)
21	VO_{2max}	Continuous variable (mL/kg/min and L/min)	K5 Cosmed (Italy) was used to collect metabolic values and a Polar V800 (Finland) was used to monitor heart rate. A graded treadmill test, where incline increased by 2% Every 2 minutes until respiratory exchange ratio (RER) of 1.0 was achieved. After RER 1.0 was reached, treadmill incline increased by 1% Every minute until volitional fatigue.

CHAPTER 4 PREAMBLE

Movement screens are commonly applied in sport and occupational contexts to inform physical training and rehabilitation programs. Expanding on the muscular and aerobic fitness study described in the previous chapter, this chapter examines another component of physical fitness, movement competency. It is possible that the increased likelihood of RSI overall, at the wrist, and at the foot in parous CAF members, identified in Chapter 2, are in part due to movement pattern differences that persist after pregnancy and childbirth. As injuries involving the foot and ankle can alter range of motion at the knee, and biomechanical changes at the knee have been observed throughout gestation, a comparison of knee movement in parous and nulliparous individuals is warranted. Thus, this study examines the relationship between medial knee displacement and parity status in an overhead squat movement screen.

Chapter 4
Is knee valgus related to parity status or injury history in female military members?

Study title: Are physical fitness, a history of childbirth, and injury history related to knee valgus in female Canadian Armed Forces members during a bodyweight overhead squat movement?

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Components of this chapter have been presented as an abstract:
"*Are parity status or injury history related to knee kinematics in a bodyweight overhead squat assessment in military servicewomen*".
International Congress on Soldiers' Physical Performance (ICSPP), London, United Kingdom., 2023

Contributions:
CME, DFdS, JP, KS, and KBA created the questionnaire used for this study.
Participant communication and scheduling was performed by CME. Study site coordination and logistics were performed by CME. Equipment procurement was conducted by KS, DFdS, and CME. Data collection for the squat test was performed by CME. Data collection for the other tests included in the protocol were performed by CME, EM, DFdS, JP, and KS. Data cleaning for the questionnaire and physical testing was performed by CME, DFsS, and JP. Video collection, calibration, overhead squat movement analysis, and data analysis for this study was performed by CME. Funding grant was procured by KBA, DFdS, KS. All authors contributed to by editing, read and approved the final version of the manuscript.

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CHAPTER 4 SUMMARY INFOGRAPH

Title:
Are physical fitness, a history of childbirth, and injury history related to knee valgus in female Canadian Armed Forces members during a bodyweight overhead squat movement

Methods:
- Data collected via questionnaire and physical fitness assessment consisting of sit-and-reach test, standing long jump, medicine ball throw, OHS, 4 RM back-squat and bench press, Biering-Sorensen test, single-leg wall sit, and a maximal incremental treadmill test (VO_{2max}).
- 2D video analysis of OHS was performed using Kinovea software.

Statistical analysis:
- 1-way ANOVA compared demographic characteristics
- 2-way ANCOVA (adjusted for age) assessed combined and individual effect of parity status and MSKi history in relationship to MKD (absolute and asymmetry).
- Pearson correlations established relationships between MKD and i) physical fitness test performance, and ii) body composition.

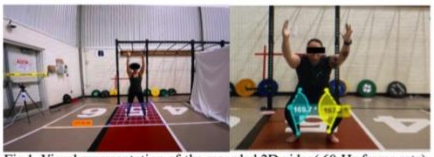

Fig 1. Visual representation of the recorded 2D video(60-Hz frame rate) and hip-knee-ankle angle measurements of OHS movement being analyzed using Kinovea software.

Participants:
- Actively serving female CAF members of Purple Trades, parous (n = 21) and nulliparous (n = 24)

Results:

MKD correlated with:
- Long jump
- Bench press

MKD related to:
- Acute injury lower extremity + Parity

MKD asymmetry related to:
- Acute injury lumbopelvic hip complex + Parity

Conclusions:
- Physical fitness (*i.e.,* lower body muscular power and upper body strength), parity status, and MSKi history are independently related to knee kinematics in female military members
- Parity status should be considered in conjunction with injury history when exploring compensatory movement patterns.

Figure 4.0 Visual summary of *Project 3"Are physical fitness, a history of childbirth, and injury history related to knee valgus in female Canadian Armed Forces members during a bodyweight overhead squat movement?"*. ANOVA = analysis of variance, ANCOVA = Analysis of covariance, CAF = Canadian Armed Forces, OHS = bodyweight overhead squat, MKD = medial knee displacement, RSI = repetitive strain injuries, RM = repetition maximum, MSKi = musculoskeletal injuries.

ABSTRACT

Objectives: A history of childbirth is associated with musculoskeletal injury (MSKi) in female members of the Canadian Armed Forces (CAF). While previous injury and pregnancy impact knee kinematics, it is unclear if a history of childbirth is associated with medial knee displacement (MKD) in an overhead squat movement screen. The aim of this study is to examine the relationship between MKD and *i*) MSKi and *ii*) parity status in female CAF members.

Methods: Twenty-four nulliparous and 21 parous female participants employed by the CAF completed a comprehensive physical fitness assessment of muscular flexibility, power, strength, endurance, aerobic capacity, and a bodyweight overhead squat movement screen (recorded using 2D video, and hip-knee-ankle angle measured using Kinovea software). Interactions between MKD, parity status, and MSKi history were assessed by one-way analysis of variance (ANOVA) and two-way ANCOVA (adjusted for age).

Results: An interaction between parity status and acute injury of the lower extremity was observed ($F = 4.379$, $p = 0.043$, $\eta 2 = 0.099$) in MKD of the right knee. The two-way ANCOVA examining acute injury of the lumbopelvic hip complex (lower back, pelvis, hip) yielded an interaction between acute injury to the lumbopelvic hip complex and parity status ($F = 4.601$, $p = 0.038$, $\eta 2 = 0.103$) in MKD asymmetry.

Discussion: Parous participants with acute injury to the lower extremity had larger MKD than parous without this injury type. Parous participants without acute injury to the lumbopelvic hip complex had greater MKD asymmetry than nulliparous without this injury type. Our findings suggest that researchers and clinicians should consider parity status in conjunction with MSKi history when assessing knee kinematics in female military members.

INTRODUCTION

Musculoskeletal injuries (MSKi) threaten operational readiness and are among the most common reasons for early release from military service.(1) In the Canadian Armed Forces (CAF), sex-disparities in MSKi type, contributing factors to injury, impact of injury on career length, and injury impeding activities of daily living have been documented.(2, 3) These findings suggest MSKi have a greater effect on female CAF members than their male peers; thus, investigating factors contributing to MSKi in females is imperative. Representation of female military personnel is insufficient in the literature(4), and the impact a history of childbirth (parity status) might have on physical fitness parameters is unexplored. Given that the majority of female CAF members are of childbearing age, examination of female **reproduction in relation to** MSKi is warranted.

Anatomical, biomechanical, and physiological changes occur during pregnancy and the postpartum period.(5-8) For example, relaxin, a hormone that increases ligament laxity, circulates at higher levels during pregnancy and could increase joint injury vulnerability. Anatomically, the positioning and shape of skeletal structures and pelvic organs shift throughout gestation.(9) This includes alterations in the spinal curvatures, such as increases in the lumbar lordosis,(10) and several changes can occur in the foot during pregnancy (i.e., length, width, volume) resulting in altered plantar pressure distribution during gait.(6-8, 11) The altered foot can persist after childbirth and are attributed to increases in body mass. Biomechanical shifts may occur with anatomical alterations in pregnancy and postpartum, including higher peak hip abductor moments and lower gluteus maximus activation.(5) Further, compared to nulliparous controls, females in their third trimester demonstrate significant differences in knee and ankle kinematics, that remain into the postpartum period.(5) Some of these changes, specifically kinetic demands of walking, may be due to increased bodyweight and endocrine system responses to childbearing.(11) Investigation of the lasting effects and breadth of these changes may help guide exercise programs aimed at mitigating fitness performance deficits and injury risk.

Physical fitness is an important consideration when assessing a military member's ability to perform job demands and identify MSKi risk. While aerobic capacity and muscular strength, endurance, or power are used to indicate fitness or predict injury, joint range of motion when performing tasks can be equally insightful.(12, 13) The overhead squat (OHS) is commonly used in such protocols as it detects mobility and coordination of multiple joints.(14) The reliability of such assessments varies between sexes, sports, and occupations, highlighting the need for population-specific research.(14, 15)

For female CAF members, the OHS could be a valuable inclusion to fitness performance assessments as a time-effective tool that assesses ankle, knee, and hip mobility. Given the changes in the kinematics of the lower extremity related to pregnancy, it may also effectively indicate differences between parous and nulliparous members. The decreases in multiplanar knee laxity and increases in anterior compliance, when comparing early pregnancy to approximately five months postpartum, suggest movements like the squat may be impacted.(16) The pregnancy-related knee and ankle kinematic changes, combined with altered muscle activation at the hip, suggest that parous females may be more likely to experience dynamic knee valgus in movements like the squat.(5, 16) Dynamic knee valgus is a risk factor for MSKi.(17) Thus, comparing knee valgus (i.e., excursion of the knee toward the midline) of parous and nulliparous females could help explain why physiological, anatomical, and biomechanical shifts resulting from pregnancy are often concurrent with bodily pain (e.g., lower back reported by up to 95% of pregnant women in some populations) and possibly injury.(10, 18, 19) As the OHS is a reliable method to screen for medial knee displacement (MKD) and demonstrates excellent sensitivity for movement dysfunction at other body regions,(20, 21) it is a strong option for rapid movement assessments conducted in military physical training environments.

This study aims to identify if MKD in an OHS movement screen is related to physical fitness (muscular and aerobic), MSKi history, or parity status in **active-duty** female CAF members.

METHODS

Data collection and recruitment

This present study was a planned sub-analysis of a larger project titled *A multi-stage approach to addressing sex-disparities in musculoskeletal injuries in military members.* Data collection was conducted via an online questionnaire (Survey Monkey, San Mateo, California) and an in-person assessment session from October 2021 to January 2022. The social networks of the research team and stakeholders, media platforms, and snowball recruiting, were used to recruit participants. The inclusion criteria for the study were: i) female sex, ii) between the ages of 18 and 55 years, iii) an active-duty member of CAF, iv) cleared to engage in maximal exercise (based on the Health Appraisal Questionnaire), v) having sustained a musculoskeletal injury while serving in the CAF, vi) providing informed consent to participate. All participants included in this sub-analysis study were employed in the Purple Trade category (provide support universally [e.g., health care, administration, military police, etc.]). Of the 66 participants who were eligible to be included in present study; OHS assessments from 21 participants were unusable due to data collection errors (e.g., camera set-up, participant position, obstruction in frame). A total of 45 participants were included in this present study. Twenty-four participants were nulliparous, and 21 had carried at least one pregnancy to 20 weeks of gestation or more (parous). Thirty-four participants had a history of repetitive strain injury (RSI), and 31 participants had sustained at least one acute injury. The following MSKi definitions were provided to participants when self-reporting injury:

i) *"Repetitive strain means injuries to muscles, tendons or nerves caused by overuse or repeating the same movement (e.g., ruck marching) over an extended period."* and

ii) *"Acute injuries… physical injuries, likely caused by a significant level of exertion or single incident of trauma, which were serious enough to require at least 24 hours off work after it to recover from."*

All procedures were approved by the local research ethics board and are in accordance with the Declaration of Helsinki.

Anthropometrics and physical fitness test protocol

Participant body weight and composition data was collected using the InBody® 570 (USA) bioelectrical impedance analyzer (BIA). Tests consisted of sit-and-reach test (best of three attempts), standing long jump (best of three attempts), medicine ball explosive power test (best of three attempts), four repetition maximum back-squat and bench press, Biering-Sorenson test (maximum time), single-leg wall sit (maximum time), and a maximal incremental treadmill test to measure VO_{2max}. Before the back-squat test, an OHS (6 repetitions) movement was administered. The OHS repetitions were performed barefoot, where the stance and depth were determined by the participant, and arms remained raised overhead with elbows fully extended. To capture movement competency within their "normal" technique for squat movement, participants were not coached prior to or during this assessment and were not informed of the purpose of this assessment. The OHS assessment was filmed, and the workflow is depicted below, and a complete summary of the protocol used for this study is included in Supplementary File 1.

Video analysis

Frontal plane, 2D video of six repetitions of the OHS was collected using GoPro Hero9 Black (GoPro, San Mateo, California) at approximately 60-Hz frame rate and edited using Adobe Premiere Pro (version 2.0, Adobe Systems Inc, San Jose, California) to remove distortion and exported as 2160p 4KUltraHD. Each video was calibrated individually, and hip-knee-ankle angle measurements (in degrees**)** were performed by the same assessor (C.M.E.) using Kinovea software. The hip-knee-ankle angle measurement was taken at the top and bottom of a squat position of the 5th repetition for each participant (Kinovea software) and angle change from top to bottom was calculated for each leg (Microsoft Excel for Mac, version 16.69.1). The difference in left compared to right leg for each repetition was then determined to assess knee movement asymmetry. The decision to assess the 5th repetition individually was made to account for movement familiarization, intra-individual variability between repetitions, and to capture potential fatigue related changes previously documented in the execution of the squat movement.(22, 23)

Data analysis

MKD and asymmetrical knee movement were assessed in relation to MSKi history (i.e., RSI or acute injury overall and stratified by body region, parity status (i.e., parous and nulliparous), and physical fitness test performance. Pearson correlations were performed to establish relationships between MKD in the 5th repetition (out of 6) and i) physical fitness test performance, as well as ii) body composition. One-way analysis of variance (ANOVA) was used to compare the demographic characteristics of parous vs. nulliparous participants. Two-way ANOVA and two-way ANCOVA (adjusted for age) were performed to assess the combined and individual effect of parity status and MSKi history in relationship to MKD, the differences in knee movement between the right and left leg through each repetition (asymmetry), and physical fitness test performance. Adjustments for multiple comparisons were performed using the Bonferroni correction, and the magnitude of potential observed differences was computed as effect sizes (eta squared, η^2). The significance level was set at $p < 0.05$. Statistics were analyzed using SPSS software, Version 27 (SPSS, Inc., Chicago, IL).

The minimum required sample size for this project was estimated based on Bagwell *et al.*, 2020 who compared the gait mechanics of 23 females through pregnancy and postpartum with 23 nulliparous controls.(5) Accepting a maximum error of ± 5%, and a desired power of 80%, the minimal sample size for each group (i.e., parous and nulliparous) was n = 24.

RESULTS

Participant demographics and characteristics are found in Table 1.

Table 1. Participant demographics and characteristics

	Parous (n = 21)	**Nulliparous (n = 24)**	**Significance**
Age	37.4 ± 7.2	33.0 ± 8.0	0.061
Height (m)	1.62 ± 0.06	1.63 ± 0.06	0.796
Weight (kg)	68.8 ±11.9	70.0 ± 11.7	0.719
BMI	25.9 ± 4.5	26.2 ± 3.9	0.832
Body fat %	29.6 ± 8.1	30.2 ± 7.1	0.791
Years of service	12.7 ± 7.8	8.8 ± 6.7	0.090
Had RSI previously (%)	76.2	75.0	0.926

Had acute injury previously (%)	71.4	66.7	0.731
Acute injury lower extremity (%)	42.9	45.8	0.841
Acute injury lumbopelvic hip complex (%)	37.5	42.9	0.714
Left MKD Rep 5	11.0 ± 10.1	16.6 ± 15.6	0.165
Right MKD Rep 5	11.6 ± 8.2	17.6 ± 1.9	0.208
Sit-and-reach (cm)	37.0 ± 5.6	35.5 ± 6.2	0.416
Long jump (cm)	154.3 ± 23.5	161.8 ± 30.2	0.367
Medicine ball throw (cm)	273.6 ± 35.1	259.5 ± 72.3	0.421
Back squat 4RM (lbs.)	149.0 ± 45.1	155.4 ± 46.8	0.650
Back squat 4RM relative to bodyweight (%)	101.5 ± 34.3	103.0 ± 32.8	0.885
Bench press 4RM (lbs.)	85.0 ± 19.5	89.4 ± 26.9	0.546
Bench press 4RM relative to bodyweight (%)	57.2 ± 13.5	59.0 ± 18.7	0.717
Biering-Sorensen (sec)	146.1 ± 62.6	106.6 ± 47.9	0.021*
Left leg wall sit (sec)	37.0 ± 26.0	33.0 ± 14.8	0.523
Right leg wall sit (sec)	40.0 ± 25.5	35.8 ± 15.5	0.501
Single-leg wall sit asymmetry (%)	39.2 ± 108.3	16.0 ± 45.3	0.342
Push-up (max repetitions)	18.9 ± 11.2	16.8 ± 11.1	0.536
VO_2max (mL/kg/min)	42.6 ± 8.8	42.5 ± 6.6	0.945

Demographic information of parous and nulliparous participants were analyzed using 1-way ANOVA for continuous variables and chi-square test was used for categorical variables. Values are displayed as mean ± standard deviation or percentage (%). RSI = repetitive strain injury, MKD = medial knee displacement (measured in degrees), BMI = body mass index, RM = repetition maximum. *Significant value $p < 0.05$.

Knee valgus and muscular fitness

Pearson’s correlation test found that greater knee valgus was related to lower performance in upper body strength (4RM bench press) and lower body power (standing long jump) (described in Table 2). No relationships between asymmetrical MKD and physical fitness test results were observed (see Supplement 2 for nonsignificant comparison findings).

Table 2. Significant correlations between medial knee displacement and physical fitness test results

OHS side	Fitness metric	n	R	p-value	95% C.I.
Left	Long jump	45	0.349	0.019*	0.061 – 0.583
	Bench press (4RM:bodyweight)	44	0.356	0.018*	0.066 – 0.590
Right	Long jump	45	0.346	0.020*	0.059 – 0.581
	Bench press (4RM:bodyweight)	44	0.323	0.032*	0.029 – 0.566

Note: Significant relationship determined using Pearson Correlation (R) between physical fitness metrics and medial knee displacement (continuous variable calculated by [Top of squat hip-knee-ankle angle - bottom of squat hip-knee-ankle angle]) during the bodyweight overhead squat assessment (repetition 5 for right and left leg). RM = repetition maximum, OHS = overhead squat, n = number of participants. *Significant finding, $p > 0.05$ (2-tailed).

Relationship between parity status and injury history with medial knee displacement

The relationships between parity status and injury history were assessed in the left and right leg using two-way ANCOVA, adjusted for age, and the Bonferroni correction was applied. Significant findings are displayed in Table 3 and described below.

Table 3. The relationship between medial knee displacement during the overhead squat with parity status and injury history

Right medial knee displacement in the bodyweight OHS			
Injury	Parity Status		
Acute Injury Lower Extremity	Parous	Nulliparous	Total
Yes	15.46 ± 7.52	10.81 ± 10.22	12.90 ± 9.19
No	8.73 ± 7.71*	23.31 ± 24.45	16.31 ± 19.53
Total	11.61 ± 8.18	17.58 ± 19.95	

Note: The results displayed represent degrees of medial knee displacement in the valgus direction. Data was descriptively analyzed using means and standard deviations. covariate of age. OHS = overhead squat. * Significant relationship of $p < 0.05$, when parous participants without acute injury to the lower extremity are compared to parous participants with this injury history.

No main effect of parity status (F = 1.071, p = 0.307, $\eta 2$ = 0.026) or acute injury to the lower extremity (F = 0.380, p = 0.541, $\eta 2$ = 0.009) for the right MKD was seen; however, an interaction between these two factors was observed (F = 4.379, p = 0.043, $\eta 2$ = 0.099). Following the Bonferroni correction, our mean difference of 7.59 (95% CI: 0.59; 14.59) was significant, indicating a larger right MKD for those with a history of acute injury to the lower extremity (i.e., thigh, knee, lower leg, ankle, foot, and toes) compared to those who have not in the parous group only. No other main effects or interactions were observed between MKD and injury history or parity status, or when parity status was combined with injury history (acute, RSI, or body regions).

Medial knee displacement asymmetry by parity status and injury history

Univariate and multivariate comparisons of MKD asymmetry in the OHS were conducted by parity status and injury history using 2-way ANOVA. Significant relationships were then adjusted by age, and the Bonferroni correction was applied (significant findings are displayed in Table 4 and described below).

Table 4. Significant relationships between medial knee displacement asymmetry in the bodyweight overhead squat with parity status and injury history

Medial knee displacement difference between left and right knees in the OHS			
Injury	Parity Status		
Acute Injury Lumbopelvic Hip Complex	Parous	Nulliparous	Total
Yes	2.31 ± 1.99	6.13 ± 11.59	4.23 ± 8.30
No	6.32 ± 12.31	1.74 ± 1.73*#	3.78 ± 8.43
Total	4.61 ± 9.43	3.39 ± 7.30	

Note: Values displayed represent degrees of medial knee displacement difference between left and right knees in the bodyweight overhead squat assessment. OHS = overhead squat.*Significant relationship of $p < 0.05$ before Bonferroni correction, #Bonferroni correction applied p = 0.065, when nulliparous participants without acute injury to the lumbopelvic hip complex compared to parous group without this injury history.

The two-way ANCOVA examining acute injury of the lumbopelvic hip complex (lower back, pelvis, hip) yielded no main effect of injury history (F = 0.024, p = 0.878, $\eta 2$ = 0.001) or parity status (F = 0.324, p = 0.573, $\eta 2$ = 0.008) in MKD asymmetry. An interaction between acute injury to the lumbopelvic hip complex and parity status (F = 4.601, p = 0.038, $\eta 2$ = 0.103) in MKD asymmetry was observed. After applying the Bonferroni correction, a mean difference of -6.89 (95% CI: -14.23; 0.46) that approached statistical significance (p = 0.065) was observed. No other main effects or interactions were observed between MKD asymmetry and injury history or parity status, or when parity status was combined with injury history (acute, RSI, or body regions).

DISCUSSION

Our findings indicate knee valgus, assessed by MKD in an OHS movement screen, is associated with physical fitness test performance, injury history, and parity status. Further, parity status should be considered in conjunction with injury history when interpreting knee movement on the frontal plane.

The relationship between OHS movement screens and jump performance has been identified previously,(24) however, the relationship between knee valgus and jumping explicitly appears to be novel to this present study. While both our protocol and the aforementioned study by Woods *et al.*, 2007(24) used a bodyweight OHS, a few important distinctions between studies should be made; namely our sample consists of adult female military members, while their participants were male athletes under the age of 18. Another difference is the paper by Wood(24) used a vertical jump test compared to the horizontal jump test used by us. Future initiatives exploring the relationship between movement screens and physical performance should consider examining sex-disparities and movement at specific joints (*i.e.,* the knee).

Our study identifies a relationship between knee valgus in the OHS and bench press relative strength. Lower body movement influencing upper limb function is not a new concept, there is a plethora of evidence supporting the importance of force transfer between the lower and upper extremities in overhead athletes (*i.e., tennis, baseball, volleyball)*.(25) The kinetic chain principle explains that body regions, such as the shoulder complex, do not work in isolation when performing tasks.(26) Instead, integration within the musculoskeletal system is required to generate force,(26) thus providing a rationale for assessments of different body regions to indicate injury risk.

Our results connecting knee kinematics (MKD on the frontal plane) to injury history and parity status, contributes new information about considerations for rehabilitation and human modeling development for female individuals. Both injury and pregnancy have been independently associated with altered movement patterns previously.(27) A preliminary musculoskeletal model of the pregnant body has even been created to estimate how gestational weight gain influences fall risk through pregnancy while walking for United States military personnel with a BMI below 26kg/m^2.(28) The authors of the model discussed the possibility of modified muscle activation through pregnancy and suggested that future projects aim to quantify these changes.(28) Kinematic and kinetic changes observed at the ankle, knee, and hip through the postpartum period identified by Bagwell *et al.,* (2020) confirm this point. Our work expands on the aforementioned studies, highlighting that a history of childbirth should be a variable included in human movement models. The interactions between parity status with acute injury to the lower extremity and **possibly the** lumbopelvic hip complex suggests that females who have given birth, and sustained an injury of this type, may compensate differently than those who have not experienced these events. Thus, virtual human models may need to include parity status and injury history when projecting movement patterns in females. In a physical rehabilitation context, it could be suggested that practitioners provide additional consideration to parous individuals with acute injury history of the lower extremity. Additionally, practitioners could utilize the OHS as a rapid assessment of movement competency when developing and assessing effectiveness of physical training programs for female servicemembers with a history of injury or childbirth. **The** directionality of the relationships between MKD and injury history was seemingly dependent on the body region impacted. These findings emphasize the need for body region and injury type to be included when assessing the interaction of MSKi and human movement in females. Factors contributing to the inverse relationships could be physical training and compensatory movements after injury and childbirth. For example, an injury to the lower extremity may encourage an individual to increase demand on the upper body. Additionally, physical therapy after injury may include coaching on joint position and exercise technique, thus influencing knee movement in the squat exercise.

The intention of this research project was to examine the characteristics of female CAF members who continued service after two main points of early attrition (childbirth and MSKi), while contributing valuable data to the dearth of literature examining female military personnel. While we are the first to explore the relationship between parity status in combination with injury history and knee kinematics, there are limitations to our findings. Our sample size did not meet the pre-determined sample size calculation that was based on the study conducted by Bagwell *et al.,* 2020 which used motion capture, force data, and surface electromyography to assess biomechanical differences of the lower extremity through gait during pregnancy (n = 20) and compared to nulliparous matched peers (n = 20). Though different methods were used, the comparison of pregnant and parous individuals with nulliparous controls was fairly novel at the time this present study was developed making Bagwell (2020) a helpful start point. The small sample size of this present study must be considered when interpreting the results. Additionally, the cross-sectional design of this study precludes the findings from determining risk and/or causation, and longitudinal information was not collected. It is possible that time since injury or childbirth, physical training after injury or childbirth, and self-selection bias all played a role in our findings. Our work provides important preliminary evidence supporting the consideration of parity status in conjunction with MSKi in human movement assessment. More rigorous biomechanics tools (e.g., electromyography) should further test these relationships to determine the mechanisms contributing to altered knee kinematics after MSKi and why childbirth may influence movement changes in response to injury. Future work examining compensations at other joints, such as the ankle, thoracic spine, or shoulders, could also provide valuable insight or expand upon our findings relating MKD with parity status and injury. Another possible limitation of this study may be that the MSKi history was collected via the pre-screening questionnaire, not medical records (access is restricted due to privacy and security rules for this population). While self-reporting of injuries may increase recall bias, self-report data has been validated against medical records of military personnel,(29) and official reporting of RSI to leadership or Health Services by female CAF members is only approximately 75%.(30) Thus, self-reporting could be an important option to capture injury in female service members. Finally, most participants included in this study were from an Army base with a high deployment and field exercise tempo. These operational demands could influence physical fitness and rehabilitation programs of the participants. Thus, the findings may not be transferable to other CAF populations.

CONCLUSION

Physical fitness (*i.e.*, lower body muscular power and upper body strength) is independently related to knee kinematics, specifically MKD, in female military members. Additionally, parity status should be considered in conjunction with injury history when exploring compensatory movement patterns. As knee valgus and movement asymmetry are known to increase injury risk in females, using the OHS to assess MKD and MKD asymmetry could be a helpful tool when developing physical training programs to rehabilitate female military personnel from MSKi and after childbirth. More research is needed to understand how human modelling algorithms should consider parity status or injury history in female individuals.

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SDC 1.

Supplemental File 1. Anthropometric measures and physical fitness assessment protocol and script.

i) **Body composition:**

Participants were asked to further remove any metal objects on their person (i.e., watch, rings, other jewelry). Individuals then stood on the InBody® (USA) bioelectrical impedance analyzer (BIA), hold the body composition analyzer arms. The BIA device directed the person on how long they needed to remain standing or if they needed to reposition. Body weight was also obtained during this test. This test was performed fasted (8 hours nothing to eat or drink).

ii) **Flexibility**: The sit-and-reach test box was be placed against a wall. With their shoes off, participants sat with the bottom of their feet against the box and their legs extended. With one hand placed over the other (palm side down), their arms outstretched parallel to the floor and directed to their toes, participants leaned forward in a slow and steady movement to briefly hold and achieve the greatest distance. Participants performed 3 attempts with a 30-second rest interval between each repetition.

iii) **Muscular power**: standing long jump and medicine ball explosive power tests was performed to assess lower- or upper-body power. For the jump tests, each subject stood at the starting position with their legs parallel and feet shoulder-width apart. Participants were instructed to bend at the knees and bring the arms behind the body. Then, with a powerful drive, they extended their legs, thrust their arms forward and jump as far horizontally as possible (standing long jump). For the standing long jump, individuals were asked to ‘hold’ the landing while the distance was measured from the start line to the back of the closest heel.

For the medicine ball explosive power test, subjects sat on a chair placed against a wall, holding a medicine ball. A tape measure was placed on the ground starting at the front end of the chair of the subject and stretched out to a distance of 15 m. With their backs against the chair for support and their feet flat on the ground, participants were advised to ‘push’ a 3 kg medicine ball, originally held at the level of the centre of their chest, away as far as possible using a motion similar to a basketball chest pass.

The best of three attempts was recorded for each power test and a 1 min rest interval allowed between repetitions.

iv) **Movement Screen:** Six continuous repetitions of a bodyweight overhead squat were performed barefoot, without coaching, and participants were blinded to what the screen was to be used for. Participants stood in a stance they would normally use to perform a squat, with arms extended above their head. The participants were instructed to squat to their normal depth, then return to the start position while keeping their arms extended. This test was recorded via video and analyzed using Kinovea at a later date.

iv) **Strength**: Four repetition maximum (RM) were performed in bench press and back squat exercises. Participants had 7 attempts for each exercise with 3-5min interval between them. Weight progression recommendations were 5 kg for bench press, and 10 kg for the back squat however participants could request different progression weights. Two or three spotters followed all the strength tests to ensure safety of the participant (one on each side of the bar and one behind during the squats). 5-10 minutes rest between the back squat and bench press tests were provided to the participants.

v) **Endurance strength**: Push-up test (maximum number of repetitions), Biering-Sorensen test (time to exhaustion), and single leg wall sit (time for each leg with 1-min interval between legs) to assess muscle endurance in both upper- and lower-body. There was a 20-minute interval between endurance strength tests and the aerobic fitness test.

vii) **Aerobic fitness**: A graded treadmill exercise test (GXT) based on Modified Balke protocol and indirect calorimetry individual's maximal aerobic capacity (VO_{2max}) was applied to measure the gold-standard maximal oxygen uptake (VO_{2max}). Expired gases were collected and analyzed using the wearable and portable metabolic system (K5, COSMED s.r.l., Rome, Italy). A Hans Rudolph (Hans Rudolph Inc, Kansas, USA) facemask and head support will be fitted on the participant and attached to the K5 unit. A Polar Wear Link and coded transmitter (Polar Electro Canada Inc, Lachine, QC) to monitor heart rate was fitted and secured around the chest beneath the participant's nipple line, next to the skin. The Polar H800 receiver (watch) was be secured to the treadmill and monitored by the assessors.

Prior to the start of the test, participants had their resting HR measured and participants were permitted to familiarize themselves with treadmill running by warming up for a period of 5 minutes. Age-predicted heart rate reserve is determined using the Karvonen method for calculating reserve: HR_{max}-HR_{rest}. While there is debate regarding accurate determination of age-predicted HRmax, when combined with $HR_{reserve}$ it can be useful in establishing an evidence- based running speed for the GXT. HR_{max} is determined using the following equation: 208-0.7*age.

Warm-up: Participants did not wear to the breathing apparatus (i.e., facemask and head support) for the warm-up, but did wear the Polar heart rate (HR) monitor. Participants started running on the treadmill at a speed of 4.0 miles per hour (mph) and speed gradually increased until they reach a comfortable warm-up speed between 5.0 – 7.0 mph.

The treadmill speed for the test was based on the speed at which the participant attained a HR greater than 75% of their age-predicted heart rate reserve during the warm-up. Immediately after the determination of initial running speed for the test, the participant was be fitted to the breathing apparatus (i.e., facemask and head support). Participants stood for 3-5 minute in a standing position to collect baseline metabolic values while allowing one to get accustomed to wearing and breathing through the mask. This standing period allowed us to ensure the values being collected were valid prior to the actual test.

Test: Using the speed determined during the warm-up, the first 2 min of the treadmill test were completed at a grade of 0%. After that, the treadmill incline increased by 2% every 2 min until a respiratory exchange ratio (RER) of 1.0 was achieved. When an RER value of 1.0 was achieved, the treadmill incline was be increased by 1% every minute until volitional fatigue, at which time the test was be terminated. At the end of each 2-min test increment, up to when an RER value of 1.0 was achieved, the participants provided a rating of their perceived exertion using a Borg Scale, as rate of perceived exertion (RPE) has been found to be a valuable and reliable indicator in monitoring an individual's exercise tolerance. RPE correlates highly with measured exercise HR and were developed to allow the exerciser to subjectively rate their feelings during exercise.

Every effort was made to conduct the test in a manner to minimize discomfort and risk. The participant was notified that they may stop the test at any time. Criteria for the termination of the VO_{2max} test included any of the following:

• onset of angina (chest pain) or angina-like symptoms

• signs of poor perfusion – light headedness, confusion, pallor (pale appearance to the skin), cyanosis (bluish discoloration); ataxia (failure of muscular coordination), nausea, or cold and clammy skin

• participant requested to stop

• volitional fatigue

• physical or verbal manifestations of severe fatigue

• failure of testing equipment

• shortness of breath, wheezing, leg cramps

• failure of HR to increase with increased exercise intensity

Any participant that displays one or a combination of any of the previously mentioned criteria for test termination was to be referred to the appropriate medical authorities on-site. Various objective and subjective indicators are useful to confirm that maximal effort has been elicited during the GXT. The following indicators were be used to confirm VO_{2max}:

• failure of HR to increase with further increases in exercise intensity

• a plateau in oxygen uptake (or failure to increase oxygen uptake by 150 ml/min) with increased workload

• an RER greater than 1.15

• an RPE of more than 17 (6 to 20 scale)

Body Composition Script

1. **Height measurement**

Script:

"Hello! My name is ____ and I will be assessing your height. Please remove your shoes and stand against this wall with your feet against the wall as close together as possible at a 45-degree angle. Please maintain 4 points of contact with the wall: your ankles, your glutes, your upper back/shoulder blades, and the back of your head. Your arms will rest by your side. Keep your chin up and look directly forward. When you are ready, take a deep breath in, then deep breath out. I will be assessing your height during the exhale. After you fully exhale you may step away from the apparatus. Please let me know if you have any questions. Thank you so much!"

Key points:

- No shoes
- 4 points of contact: Ankle, bum, upper back, back of head
- Feet should be as close together as possible (the feet will be sitting right beside the pole running down the middle of the apparatus) at a 45-degree angle
- Arms should be by the side
- Chin up, looking directly forward
- *** As the participant inhales, keep a hand on the headpiece. As they exhale, move the headpiece down as the participant's height shrinks. Once they have fully exhaled, they can step forward and this will be the height you will record.

2. **Body Composition Scale (InBody 570)**

Script:

"Hello! My name is ____ and I will be assessing your body composition. Please remove your shoes and socks. Please ensure that you remove all pieces of metal that you may have on your body, including jewelry and accessories (e.g. watch). Once done, I will ask you to step on the body composition machine with your feet lined up at the metal footsteps. The apparatus will assess your weight and then we'll enter your information. Next, the machine will assess various body composition measures. I'll ask you to hold these handles, ensuring your arms are at a 45-degree angle from your body. The apparatus will play a lovely tune. Please don't move or talk during this measurement time. Once done, I will take the handles from you, and you will be able to step off the machine. Please let me know if you have any questions. Thank you so much!"

Key points:

- Make sure to turn the machine on – the ON switch is located at the back of the machine
- Before starting the tests, there is a small little circle in front of the footsteps – ensure the red dot is centered in this circle (circled in red above)
- Must be barefoot
- NO metals!!
- Make sure feet are lined up on the footsteps.
- *** When the participant is holding the handles, their arms must be at a 45-degree angle such that their arms are NOT touching their torso.
- Don't talk to the participant during the test and make sure they don't talk or move
- The machine will talk and tell you what to do, so if you ever get lost you can always just follow that.

- ***Ensure the participant urinates within 30 minutes prior to the test (i.e. let them urinate before the test if they need to).

SNACK BREAK – water and food allowed.

Warm-up

Dynamic

1) 2x20m Jog
2) 20m "butt kickers"
3) 20m high knees
4) 2x20m lateral shuffle (switch sides at 20m)
5) 20m walking lunges
6) 20m skips

Stretching/Mobility

1) Lunge with T-spine reaches 2x(3 reps/side, pause 3 seconds at top and bottom of the reaches)
2) Low-Lunge with Pyramid 2x(3 reps/side, 5 second hold each rep.)
3) High-plank position (5-10 seconds)

Specific

4) Hand release push-ups (3 reps): Lower for 3 sec, hands lift, hands down, press up, hold plank for 3 sec.
5) Plank-to-Deep Squat w/ overhead reach (4 reps, 5 second pause in Squat and Plank positions)
6) Deep Overhead Squat-Toe Grab Forward Fold (3 reps)

Sit and Reach

Start position

1) Sit on floor with both feet against the back of the sit-and-reach bench.
2) Sit-up straight with legs extended and touching the floor

Movement

1) Place hands palm-over-palm (one on top of the other)
2) Slide the marker forward with both hands, ensuring knees do not bend
3) When at "end range" pause for 2 seconds.

This test is performed 3 times, with the best result used.

Long Jump

Start Position

1) Stand with toes on the start line.
2) Feet approximately shoulder-width apart

Movement

1) In one fluid motion, swing both arms backwards while bending your knees (practice once or twice)
2) Jump as far forward as possible,
3) Land with both feet
4) Stay on landing point until the measurement has been taken.

This test is performed 3 times, with the best result used. Measurement is to the rear heel.

Medicine Ball Test

6lbs medicine ball

Start

1) Chair is positioned with back rest against a wall.
2) Sit with both feet flat on the ground with back fully against the backrest
3) Holding the medicine ball, extend arms away from the chest
4) Drop the ball.

Movement

1) Holding the medicine ball at chest height,
2) Perform a chest pass to push/toss the ball as far forward as possible.

This test is performed 3 times, with the best result used.

Overhead Squat protocol

Note: This test also acts as a competency check for the back squat. Address safety concerns after the movement screen is complete and before back squat instructions.

START VIDEO RECORDING

Scenario 1

Start Position

1) Shoes off.
2) Stand with your feet as they would normally be placed for your squat.
3) Raise your arms overhead, with elbows fully extended (no bend in elbows).

Movement

4) Squat to your normal depth and return to starting position.
5) Perform 6 repetitions.

Script: *"You are about to perform a bodyweight squat movement.*

Standing as you normally do to perform a squat, raise your arms above your head and keep them straight as you squat to your usual depth. Keeping your arms raised and elbows extended return to standing. You will perform 6 continuous repetitions. Each rep counts at the top, please keep your arms up until you finish your last rep. Do you have any questions?"

Count repetitions out loud.

NOTE: FOR STRENGTH TESTS, USE EDI (EXPLAIN-DEMONSTRATE-IMITATE).

Back Squat

Note: Teach and demonstrate the back squat prior to participant completing this stand. Coaching is permitting. Ask if they have completed a back squat before.

Start Position

1) Stand under the bar with bar across the center of the shoulders
2) Ensure entire body is under the bar
3) Prior to lifting the bar, inhale to expand the lungs and hold until you have set up
4) Stand erect with the chest and belly filled with air
5) Take one or two steps away from the rack to set up

Barbell position:

High Bar Squat: The bar sits on top of the trapezius muscles near the base of the neck (increases force at the knees)

OR

Low Bar Squat: The bar sits 1 – 2 in. below the deltoids (increases force at the hips)

Movement

Descent (down)

1) Push hips back
2) Simultaneously flex knees while pushing hips back
3) Maintain torso angle throughout lift
4) Distribute bodyweight from the balls of the feet to the heels
5) Maintain slow, controlled descent
6) At the bottom, do not bounce, jerk, or stop the motion ('bottom' is 90 degrees at the knee)

Ascent (up)

1) Drive feet into the floor
2) Simultaneously raise hips and shoulders
3) Push shoulders slightly back into the bar so chest remains facing outward
4) Continue extending hips and knees
5) Maintain proper head and eye position
6) Stand erect and back into the start position

Each 4RM attempt will have 3-5 minutes between.

STOP VIDEO RECORDING

5 MINUTE REST

Bench Press

Note: Teach and demonstrate the bench press prior to participant completing this stand.

Coaching is permitting. Ask if they have ever done a bench press before.

Start Position

1) Lie flat on the bench in a five-point body contact position with eyes directly under the bar

2) Grasp the bar evenly with a closed, pronated grip with hands slightly wider than shoulder-width
3) Lift the bar from the hooks and position it directly above shoulders with elbows fully extended

Movement

1) Take a deep breath to fill the chest with air and engage the core to prevent the back from arching
2) Lower the bar slowly and under control until elbows are in line with the torso
3) Keep wrists rigid and directly above elbows
4) Drive the weight explosively away from the chest by extending elbows
5) Exhale as you near the top of the lift

Each 4RM attempt will have 3-5 minutes between.

10 MINUTE REST

Biering-Sorensen Test (Endurance)

Start Position

1) Lay prone on the bench,
2) Upper half of body (from the anterior superior iliac spine) will be off the elevated platform and the legs will be on the elevated platform.
3) Place legs as close together as possible
4) Straps will be placed around the ankles, crease of the knees, and top of the thighs,

Movement

1) When ready, lift the upper body off the chair, while placing your hands across your chest or beside your body,
2) The test time begins when the upper body is suspended (no longer supported)
3) Hold your upper body in a neutral position for as long as possible.

The test is terminated if: excessive fatigue, you develop back pain or similar pains that are too great, if your touch the chair/floor with your hands, or if your neutral position changes.

This test has 1 attempt.

Single Leg Wall Sit (Endurance)

Start Position

1) Find a space on the wall.
2) Stand with feet comfortably shoulder-width apart with back against wall
3) Slide down the wall until knees are at a 90 degree angle (instructor will check to make sure position is good)

Movement

When ready, lift one leg of your choosing.

4) The test time begins when one leg is lifted
5) Test time stops when the foot touches back on the ground.
6) 1 minute is required between attempts for left and right.
7) Repeat for the other side.

This test has 1 attempt.

Push-up Test (Endurance)

The purpose of this test to achieve as many repetitions as possible without stopping (Fluid motion).

Start Position

1) Starting in the high-plank position
2) Hands on the ground and slightly wider than shoulders,
3) Knees extended, not on the ground
4) Feet comfortable distance apart.

Movement

5) Lower down to a 90-degree angle at the elbows,
6) Return to high-plank position.
7) The test is terminated when continuous motion stops

-Each repetition is counted at the return to high-plank position.

-Feet and hands must not lift from the ground

-Whole body must lower and lift for the rep to count

-Knees cannot touch the ground during the test.

This test has 1 attempt.

REST and bring to K5

K5 Trial Script

Before Participant

K5 warm up

1) Warm-up K5 device (about 75min if 1st time of the day; 30min if turned off between tests in the same day)
    - Run on lab mode – K5 will be plugged into the computer via USB cable
    - Use Omnia software

Before 1st assessment:

2) Perform flowmeter calibration;
    - Attach the transparent tube
    - Attach the cone piece at the end of it
    - Attach the flowmeter to the cone piece
    - Take 6-12 strokes, check to see if the calibration passed, if failed check for leaks
3) Perform scrubber calibration;
    - Attach the CO_2 scrubber to the sampling line
    - Check to see if the calibration passed, if failed shake the scrubber for 10 secs
4) Perform gas calibration;
    - Choose bxb
    - Wait for instructions on the screen to ask to connect the sampling line and open the valve
    - Wait until calibration ends, close valve, remove sampling line

Before each assessment (from 2nd and beyond):

5) Re-do flowmeter calibration (because turbine is changed);

If K5 is turned off and back on for a subsequent test at the same day:

6) Re-do scrubber calibration;

If drastic changes in the temperature or humidity happen through the same day:

7) Re-do gas calibration;

With Participant

Collect resting HR

1) Have participant put on polar HR monitor on the rib cage underneath their chest*

RA: I am going to place a HR monitor on your rib cage directly underneath your chest. If the strap feels uncomfortable, please feel free to adjust it.

RA: If you could take a seat I will collect your resting HR. Just sit down and relax. This process will take about 3 mins.

2) Observe HR on Polar watch, record lowest HR, perform calculation for max HR (HRmax=208-0.7*Age), 60% of HRmax (HRR*0.6+restingHR) and 75% of HRmax (HRR*0.75+restingHR)*

   Note: Heart rate reserve (HRR): HRmax-restingHR

Assess baseline

1) Assess baseline of participants without the mask
2) A HR between 60% of HRmax and 75% of HR max is the target and at that speed the test will be performed
3) The baseline assessment will last 5 minutes

Software setup

1) Open COSMED OMNIA
2) Select 'Database'
3) Select 'New Subject'
4) Insert ID1 and ID2, DOB, gender, and ethnic group, Select 'OK'
   - DO NOT ADD NAME
5) Insert height and weight
6) Select 'New Test'
7) Select 'Cardio Pulmonary Exercise Testing'
8) Select 'CPET-Breath by Breath'
9) At the beginning of the resting select 'Start' then 'Rec'
10) Throughout the test place markers at end of the rest and end of each stage, place a marker by selecting 'Marker' and labeling it accordingly (ex. 'End of rest', 'Stage 1')

Perform VO2 max test

RA will provide encouragement throughout the test as RER and RPE increase

1) Place mask on participant
2) Adjust mask and check for leaks
3) Connect mask to K5
4) Collect resting VO2 for 5 mins
5) Start the VO2 max test with the pre-determined speed
6) The test will commence with a 2-minute interval with a grade of 0

7) With 30 seconds left in each stage the RA will collect RPE, RER, and HR
8) Every two minutes the grade will increase by 2% until RER=1.0, at which time the stages will decrease to 1-minute and the grade will increase by 1% only
    - The RA can stop recording RER, RPE and HR
9) When the participant stops, the RA will stop collecting VO2 and record the HR
10) A cool down will be performed by the participant for 5 mins

SDC 2.

Supplemental file 2: Relationships between physical fitness metrics and medial knee displacement.

OHS Rep, side		Body fat (%)	Sit & reach (cm)	Long jump (cm)	Medicine ball throw (cm)	4RM Back squat (lbs.)	4RM Back squat relative to bodyweight (%)	4RM bench press (lbs.)	4RM Bench press relative to bodyweight (%)	Biering Sorenson (sec)	Left leg wall sit (sec)	Right leg wall sit (sec)	Push-ups (reps)	VO2max (mLkgmin)	VO2max (L*Min)
5, LvRt	R	-0.007	-0.051	0.066	0.103	-0.145	-0.164	0.011	-0.048	0.065	0.08	0.07	0.023	-0.090	0.097
	P-value	**0.964**	**0.742**	**0.666**	**0.501**	**0.354**	**0.293**	**0.943**	**0.758**	**0.670**	**0.601**	**0.649**	**0.883**	**0.581**	**0.550**
	N	45	45	45	45	43	43	44	44	45	45	45	45	40	40
5, L	R	-0.096	0.128	0.349*	0.114	0.069	0.155	0.243	0.356*	-0.073	-0.225	-0.219	0.21	0.031	-0.135
	P-value	**0.529**	**0.402**	**0.019**	**0.457**	**0.662**	**0.321**	**0.112**	**0.018**	**0.636**	**0.138**	**0.148**	**0.165**	**0.848**	**0.407**
	N	45	45	45	45	43	43	44	44	45	45	45	45	40	40
5, Rt	R	-0.174	0.102	0.346*	0.151	0.044	0.116	0.229	0.323*	-0.018	-0.157	-0.170	0.177	0.115	-0.079
	P-value	**0.254**	**0.506**	**0.020**	**0.321**	**0.782**	**0.458**	**0.134**	**0.032**	**0.909**	**0.303**	**0.265**	**0.244**	**0.480**	**0.627**
	N	45	45	45	45	43	43	44	44	45	45	45	45	40	40

Note: Relationships determined using Pearson Correlation (R) between physical fitness metrics and medial knee displacement (continuous variable calculated by [Top of squat hip-knee-ankle angle - bottom of squat hip-knee-ankle angle]) during the bodyweight overhead squat assessment (repetitions 4, 5, and 6 [of 6] for right and left leg). RM = repetition maximum, OHS = overhead squat, LvRt = medial knee displacement left compared to right, Rt = right, L = left, Significance set to 0.05 (2-tailed).

CHAPTER 5 PREAMBLE

First-responders and military personnel are often grouped together in literature reviews and research on either population are often used to inform initiatives for both populations. The next aim of this thesis was to explore if the relationships between injury history, parity status, and physical fitness identified in Chapter 3 also apply in a non-military sample. To conduct a direct comparison in the future, the physical fitness of females employed in non-military occupations that are similar to the CAF Purple Trades (i.e., law enforcement officers, paramedics, firefighters, healthcare providers) was assessed by the same tests for body composition, muscular fitness, and aerobic capacity used in Chapter 3. To note, the overhead squat movement assessment described in Chapter 4 was not included in the protocol for the non-military group. The location used for data collection a shared lab space with multiple ongoing research projects often being administered at the same time. Video capture in that environment would not have been feasible.

Chapter 5

Reproductive Health, Musculoskeletal Injury, and Fitness of Female Personnel Employed in Arduous Non-Military Occupations

Study title**:** Injuries, Exercise, and Reproductive Health are Related to Physical Fitness of Female First Responders and Health Care Providers

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Contributions:
CME and JLP created the questionnaire used for this study. Participant communication and scheduling were performed by CME. Study site coordination and logistics were performed by CME. Data collection was performed by CME, JLP, .M, MA, NO, and MLM. Data cleaning and analyses were performed by CME. The principal investigator for this project was CME, supervised by KBA. All authors contributed to by editing, read and approved the final version of the manuscript.

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CHAPTER 5 SUMMARY INFOGRAPH

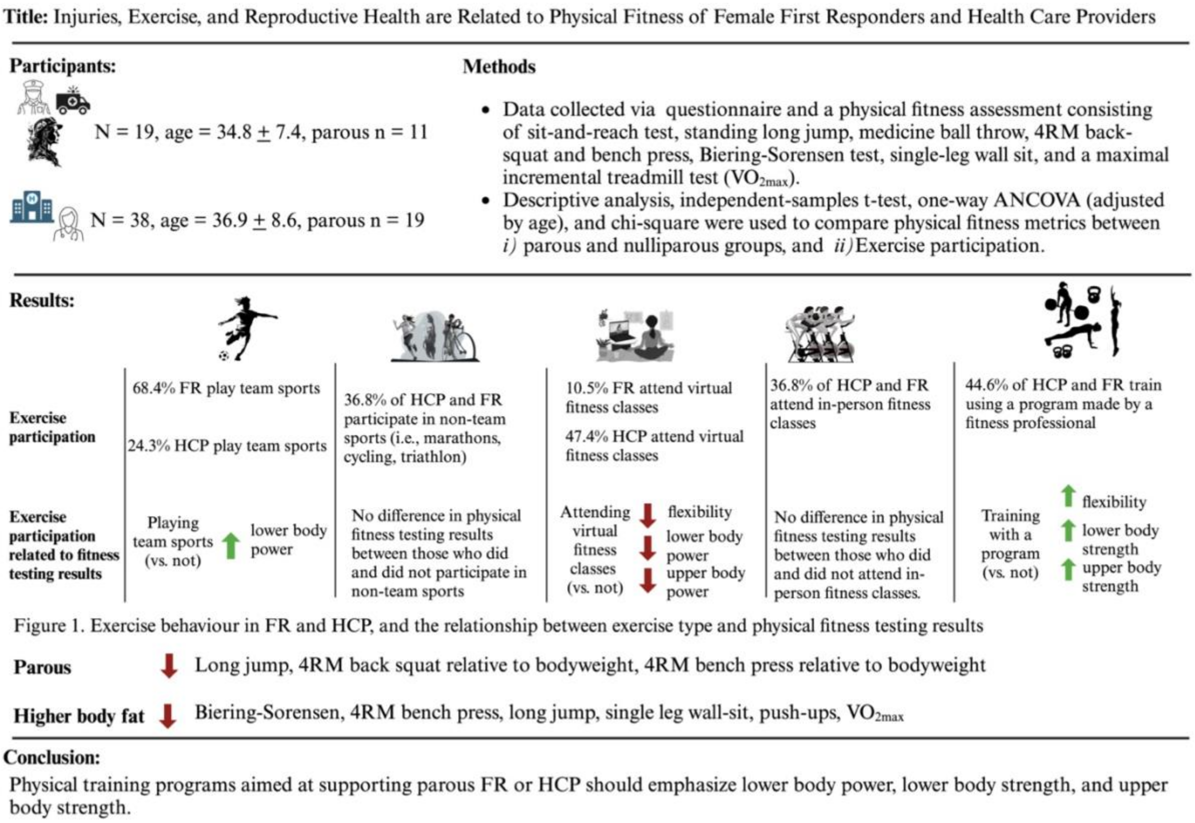

Figure 5.0 Visual summary of *Project 4"Injuries, Exercise, and Reproductive Health are Related to Physical Fitness of Female First Responders and Health Care Providers?"*. ANCOVA = Analysis of covariance, RSI = repetitive strain injuries, RM = repetition maximum, MSKi = musculoskeletal injuries.

ABSTRACT

Introduction: Musculoskeletal injuries (MSKi) are the most common injury type experienced by first-responders and healthcare providers (HCP), making them a significant threat to physical and mental wellbeing. Female reproductive health and injury history have been related to physical fitness in female members of the Canadian Armed Forces. This relationship has not been explored in Canadian protective services personnel (first-responders) or healthcare providers.

Methods: Fifty-seven females employed as firefighter, paramedic, law enforcement, or healthcare provider completed a physical fitness protocol to assess: *i)* muscular power (standing long jump and medicine ball throw), *ii)* muscular strength (4 repetition maximum back squat and bench press), *iii)* muscular endurance (Biering Sorenson test, single-leg wall sit, and push-ups), *iv)* flexibility (sit-and-reach), and *v)* aerobic capacity (graded treadmill VO_{2max} test). Spearman *rho* correlation analyses were applied to Descriptive analysis, independent-samples t-test, one-way ANCOVA (adjusted by age), chi-square, and Spearman *rho* correlation analyses were used to compare physical fitness results for female reproductive health history (*e.g.,* parity status), previous MSKi, and physical activity behaviours (*e.g.,* sport participation). A p-value <0.05 is considered significant.

Results: A history of childbirth, body composition, and exercise behaviours were related to physical fitness (*i.e.,* standing long jump, Biering Sorenson, bench press, and back squat) in law enforcement, firefighting, paramedicine, and healthcare personnel.

Conclusions: Physical training programs aimed at supporting parous first-responders or healthcare providers should emphasize lower body power, lower body strength, and upper body strength.

INTRODUCTION

Musculoskeletal injuries (MSKi) are the most common injury type experienced by first-responders and healthcare providers (HCP), making them a significant threat to physical and mental wellbeing. The occupational injury rate of firefighters is 3-7 times greater than the national average,(1) police have a 10% greater prevalence of injury than firefighters,(1) and the number of lost-time claims due to injury reported by HCP was more than double of all other industries (non-military) combined.(2) While advanced age and service years have been correlated with reduced injury incidence in these occupations, female individuals employed in these roles seem to be at greater risk.(1, 3)

Proposed factors contributing to the increased injury risk in females compared to males are muscle activation patterns, anatomical structure, hormone differences, including those associated with the menstrual cycle, and other events associated with female reproduction (e.g., pregnancy and the postpartum).(4) For example, female military members who have irregular menstrual cycles or have given birth (parous) are more likely to sustain repetitive strain injuries (RSI).(5, 6) To the best of our knowledge, the relationship between female reproductive health and MSKi has not been explored in Canadian first-responders or healthcare providers.

When reasoning why parous individuals employed in arduous occupations sustain more MSKi compared to nulliparous peers, physical fitness decline during pregnancy and postpartum must be considered.(7) Muscular strength, power, endurance, and aerobic capacity have all been associated with injury incidence and prevalence in personnel employed in arduous occupations.(1, 8-11)

While physical demands vary between these professions, those employed in these roles benefit from a high fitness level. The day-to-day activities of a paramedic in Canada consists of sedentary periods (i.e., driving) and high-physical demand elements such as carrying 13 kg cardiac monitor or possibly a team lift of stretcher and large patient (200kg) over a curb.(12) Low levels of physical fitness can negatively impact job performance and increase the risk of injury.(1, 8, 13, 14) In policing, higher physical fitness test results are associated with superior marksmanship, including better scores on the decisional shooting test (officers perceive and identify specific targets or threats, distinguishing from non-viable targets).(15) As the evidence supporting specific physical fitness attributes as protective against injury, such as lower body power or consecutive push-up repetitions, females are severely underrepresented in the literature for individuals employed in arduous occupations.(8, 16, 17) The few studies that include females suggest the ability for a physical fitness test ability to predict injury can be sex-dependent.(8, 9, 16, 17) Research examining optimal exercise methods and physical activity habits supporting occupation performance and injury reduction is equally distorted towards males. This lack of female-specific data highlights a problematic sex-bias when attempting to create evidence-based physical training programming, policy, and procedures.

Ultimately, the presence of females in arduous occupations is increasing and the number of female individuals choosing to continue careers after childbirth is on the rise in Canada.(18) Research aimed at reducing the burden of MSKi and understanding the impact of female reproductive health in these occupations is needed. Thus, the purpose of this study is to examine how physical health (reproductive health factors, anthropometric measures, MSKi history) and exercise behaviour influence physical fitness in first-responders and HCP (as defined by the Province of Ontario; https://www.ontario.ca/page/regulated-health-professions). We hypothesize that measures of physical fitness will differ by parity status, body composition and career. We predict outcomes will favour those who are nulliparous, have lower body fat composition, and work as first-responders. Exercise behaviours will also be examined to account for physical adaptations that might occur from strain applied to tissues not in an occupation context.

METHODS

Recruitment was conducted via the research lab's social media accounts (e.g., lab website, Facebook, Twitter), the social networks of the researchers, and 'snowball' recruiting. The inclusion criteria consisted of: (i) biological sex of female, (ii) being between the ages of 18 and 55 years, (iii) being employed as a healthcare provider (regulated health professional currently practicing in the province of Ontario [e.g., medical doctor, nurse, kinesiologist, physiotherapist, chiropractor]), fire fighter, law enforcement officer, or paramedic, (iv) being cleared to engage in maximal exercise (based on the pre-screening questionnaire), and (v) providing informed consent to participate (in English or French). The exclusion criteria for this study were as follows: diabetes (any type), untreated thyroid disease, cardiovascular diseases, being pregnant, and contraindication to exercise.

All procedures of the present study have been reviewed and approved by the University Research Ethics Board (H-11-20-6180) and were conducted in accordance with the Declaration of Helsinki.

Data pertaining to female reproductive health (e.g., pregnancy, menstrual cycle, hormonal birth control use), occupation, physical activity and exercise participation, and MSKi history were collected via self-report questionnaire. When available, average daily step counts and physical activity minute data for the year were obtained via participant smartwatch history. The following MSKi definitions were provided to participants when self-reporting injury:

i) *Repetitive Strain or Overuse Injuries - injuries to muscles, tendons or nerves caused by overuse or repeating the same movement (e.g., ruck marching) over an extended period. For example, carpal tunnel syndrome, tennis elbow, plantar fasciitis, or tendonitis.*

ii) *Acute Injuries – serious physical injuries, likely caused by a significant level of exertion or single incident of trauma, which were serious enough to require at least 24 hours off work after it to recover from. For example, a broken bone, a sprain.*

Participant body weight and composition data was collected using the InBody 520^{TM} (USA) bioelectrical impedance analyzer (BIA). Bone mineral density (BMD) was measured using dual-energy X-ray absorptiometry (DXA). Physical testing was performed to assess: *i)* muscular power (standing long jump and medicine ball throw), *ii)* muscular strength (4 repetition maximum back squat and bench press), *iii)* muscular endurance (Biering Sorenson test, single-leg wall sit, and push-ups), *iv)* flexibility (sit-and-reach), and *v)* aerobic capacity (graded treadmill VO_{2max} test) (see Appendix A, SDC1, a detailed description of the protocol).

The physical fitness and body composition protocol used for this present study were chosen based on the findings of a scoping review conducted by our lab and was used previously with a female military population.(10) The minimum required sample size for this project was estimated based on an ongoing project occurring in our lab which assessed the relationship between parity status and physical fitness in Canadian Armed Forces members. Accepting a maximum error of ± 5%, and a desired power of 90%, the minimal sample size for was n = 48, 24 who have not given birth (nulliparous) and 24 who have given birth (parous).

Statistical Analysis

For MSKi analysis, injuries were stratified by type (acute or RSI), body region, and body complex: *i)* head, neck, shoulder, *ii)* upper extremity (fingers, thumb, hand, wrist, lower arm, elbow upper arm, shoulder), *iii)* spine (low back, upper back, neck), *iv)* lumbopelvic hip complex (low back, pelvis, hip), and *v)* lower extremity (hip, thigh, knee, lower leg, ankle, foot, toes). Menstrual cycle length and frequency were categorized by *i)* regular: within the last year, cycle is consistently between 21-35 days, and *ii)* irregular: within the last year, at least 1 cycle has been outside of 21-35 days (not related to pregnancy). Parity status was defined as *i*) parous: has carried at least 1 pregnancy for 20 weeks, and *ii)* nulliparous: has not carried a pregnancy for 20 weeks.

Normality (Shapiro-Wilks) and variance (Levene's test) assumptions will be used and if non-normally distributed, t-tests will be used to compare the means of continuous descriptive variables as they are considered robust enough for non-normal data.(19) Significant results from the t-test will then evaluated for ANCOVA. The bivariate associations for 2x2 tables will be analyzed with Chi-square test or Fisher's Exact test (when the assumption of having <20% of the cells with an expected count of less than 5 is not met). Significant findings in the Chi-square test will then be assessed using logistic regression analysis when assumptions are met. Numbers and percentages will be used to describe categorical variables. Means and standard deviations will be used to describe continuous variables. Spearman *rho* correlation analyses will also be performed to describe the strength and direction between continuous variables (e.g., anthropometric measures and fitness results). A p-value <0.05 is considered significant.

RESULTS

Participant Demographics

A comparison of participant demographics, split by occupation, are presented in Table 1.

Table 1. Participant demographics

Variable	First responder		Healthcare provider		
	N		**N**		**p-value**
Age (years), mean ± SD	19	34.8 ± 7.4	38	36.9 ± 8.6	0.361
Height (m), mean ± SD	19	167.3 ± 7.7	38	165.9 ± 6.0	0.529
Body weight (kg), mean ± SD	19	73.2 ± 13.3	38	67.3 ± 9.4	0.092
Body fat (%), mean ± SD	19	26.0 ± 9.1	38	28.1 ± 8.7	0.411
BMI (kg/m^2), mean ± SD	19	26.1 ± 4.1	38	24.2 ± 3.7	0.104
Occupation start (year), mean ± SD	19	2012.7± 7.4	38	2012.7 ± 7.5	0.990
Skeletal muscle (%), mean ± SD	19	40.3 ± 6.6	38	39.7 ± 5.5	0.737
Total body BMD (g/cm^2), mean ± SD	18	1.27 ± 0.111	34	1.21 ± 0.092	0.064
Femur neck BMD (g/cm^2), mean ± SD	18	1.06 ± 0.113	34	1.02 ± 0.108	0.208
L2-L4 lumbar BMD(g/cm^2), mean ± SD	18	1.31 ± 0.135	34	1.23 ± 0.140	0.051
1/3rd radius BMD (g/cm^2), mean ± SD	18	0.720 ± 0.047	34	0.703 ± 0.052	0.231
Parity Status					
1 or more births (%)	11	57.9	19	50.0	0.574
Never given birth (%)	8	42.1	19	50.0	
Given birth within 1 year					
Yes (%)	2	10.5	3	7.9	1.000
No (%)	17	89.5	35	92.1	
Menstrual cycle periodicity					
Regular (%)	11	57.9	18	42.1	0.146
Irregular (%)	8	42.1	20	52.6	
Hormone birth control use					
Yes (%)	10	52.6	20	52.6	
No (%)	9	47.4	18	47.4	1.000
No (%)	4	21.1	9	23.7	

Note: T-tests were used to compare means of continuous descriptive variables. Bivariate associations for 2x2 tables were analyzed using a Chi-square test or Fisher's Exact test (2-sided). BMI – body mass index, FR- first responder, HCP- healthcare providers, BMD – bone mineral density. Regular menstrual cycle periodicity = within the last year, cycle is consistently between 21-35 days. Irregular menstrual cycle periodicity = within the last year, at least 1 cycle has been outside of 21-35 days. None of the participants have reached menopause.*Significant difference p-value <0.05.

Occupation

Nineteen participants were included in the first-responder group and 38 in the healthcare provider group. Physical fitness comparisons are displayed in Table 2 (significant findings only) (see table Appendix B, SDC 2, physical fitness results by occupation, parity status, hormone birth control use, menstrual cycle length and frequency).

Table 2. Significant differences in physical fitness test performance between first responders and healthcare providers

Fitness Metric	First responders (n = 19)	Healthcare Providers (n = 38)	Significance
Medicine Ball Toss (cm)	294.7 ± 45.6	244.6 ± 48.7	<0.001*
4RM Back Squat (lbs.)	172.63 ± 36.8	207.8 ± 61.8	0.009*
4RM Bench Press (lbs.)	110.0 ± 28.3	86.3 ± 20.3	0.003*

Note: T-tests (2-sided) were used to compare means of physical fitness test results of participants employed as a first responder or healthcare provider. 4RM = 4 repetition maximum.*Significance set to <0.05.

Musculoskeletal Injuries

Acute injuries were reported by 77.2% of participants, **and of** the 57 participants included in this study, 78.9% had sustained at least 1 injury within the last 12-months (see table Appendix C, SDC 3, comparisons of body regions injured by occupation and female reproductive health factors). Note that more first-responders sustained MSKi in the last year (94.7% vs. 71.1%, p = 0.045) and RSI overall (94.7% vs. 71.1%, p = 0.045) compared to the HCP group. No differences by reproductive health marker for overall RSI, acute injury or having sustained an injury in the last year.

Participants with a history of back injury performed better on the medicine ball toss test (286.2cm ± 46.9 vs. 240.4cm ± 49.1, p <0.001). A history of lumbopelvic hip injury yielded lower times for the Biering-Sorenson test (151.3sec ± 48.9 vs. 182.9 ± 67.1, p = 0.047). No other injuries, overall or within the last 12-months, were associated with physical fitness (see table Appendix D, SDC 4, physical fitness results by musculoskeletal injury stratified by body region).

Exercise Behaviours

Table 3. Physical activity and exercise participation for first responders and healthcare providers

Variable	N	First responder	N	Healthcare Practitioner	p-value
In-person fitness classes					
Yes (%)	8	42.1	13	34.2	0.560
No (%)	11	57.9	25	65.8	
Virtual fitness classes					
Yes (%)	2	10.5	18	47.4	0.008*
No (%)	17	89.5	20	52.6	
Follow a PT program made by a fitness professional					
Yes (%)	11	61.1	14	36.8	0.088
No (%)	7	38.9	24	63.2	
Team sports (in the last year)					
Yes (%)	13	68.4	9	24.3	0.001*
No (%)	6	31.6	28	75.7	
Non - team sports i.e. marathon, cycling, triathlon (in the last year)					
Yes (%)	10	52.6	11	28.9	0.081
No (%)	9	47.4	27	71.1	
Taught or coached how to do a squat previously					
Yes (%)	18	94.7	32	84.2	0.405
No (%)	1	5.3	6	15.8	
Taught or coached how to do a push-up previously					
Yes (%)	16	84.2	27	71.1	0.343
No (%)	3	15.8	11	28.9	
Average daily physical activity minutes, mean ± SD	8	62.5 ± 39.3	17	50.5 ± 25.2	0.447
Average daily step count, mean ± SD	14	8578.5 ± 1790.1	23	9166.9 ± 3249.2	0.483

Note: T-tests were used to compare means of continuous descriptive variables. Bivariate associations for 2x2 tables were analyzed using a Chi-square test or Fisher's Exact test (2-sided). FR- first responder, HCP- healthcare providers, PT – physical training.*Significant difference p-value <0.05.

Physical activity and exercise participation by occupation are outlined in Table 3. Exercise and physical activity behaviours were associated with fitness test performance and significant relationships are described below **(**see table Appendix E, SDC 5, Physical fitness results by exercise behaviour**)**. Superior long jump was seen in those who participated in team sports

(169.9cm ± 23.5 vs. 152.5cm ± 24.9, p = 0.012). Poorer sit and reach (33.6cm ± 7.5 vs. 38.3cm ± 6.9, p = 0.028), long jump (145.5 cm± 18.8 vs. 166.5 ± 25.7, p = 0.002), and medicine ball toss (236.7cm ±55.4 vs. 274.6 ± 47.2, p = 0.004) were observed in participants who reported attending fitness classes virtually. Participants currently following a physical training program created by a fitness professional performed better in: 1) Sit and reach (40.0cm ± 5.3 vs. 33.9cm ± 8.0, p <0.001), 2) Absolute weight lifted in the 4RM back squat (203.5lbs ± 50.6 vs. 167.6lbs ± 42.2, p = 0.005), 3) Weight lifted in the 4RM back squat relative to bodyweight (134.9% ± 33.8 vs. 112.0% ± 29.8, p = 0.009), 4) Absolute weight lifted in the 4RM bench press (107.2lbs ± 22.6 vs. 83.7lbs ± 23.8, p <0.001), 5) Weight lifted in the 4RM bench press relative to bodyweight (71.2% ± 16.5 vs. 56.1% ± 17.2, p = 0.002). No relationships were observed between attending fitness classes in person and the test battery.

Anthropometrics

Higher skeletal muscle mass percentage was observed in participants who participated in team sports within the last year (42.2% ± 4.9 vs. 38.4% ± 6.1, p = 0.021) and in those who adhere to a physical training program created by a fitness professional (42.3% ± 4.7 vs. 37.9% ± 6.1, p = 0.005). Other types of exercise and daily physical activity minutes recorded on smartwatches were not associated with anthropometrics or body composition. However, higher body fat % (*rho* = -0.403, p = 0.013) and higher BMI (*rho* = -0.340, p = 0.039) were correlated with lower average daily step count for the last year (recorded by smartwatches). To note, having been coached previously on how to perform a push-up or a, participation in organized team sports (within the last year), and participation in organized non-team sports (ex. Triathlon, marathon, cycling) were not related to MSKi (acute or RSI).

Body fat percentage, skeletal muscle mass percentage, body mass index (BMI), height, bodyweight, and BMD were all correlated with physical fitness test performance (Table 4).

Table 4: Correlations between anthropometric measures and physical fitness test performance of female first responders and healthcare providers assessed using Spearman *rho* analysis.

Continuous variable	Mean ± SD		Sit and Reach (cm)	Biering Sorenson (sec)	Bench Press 4RM (lbs.)	Back Squat 4RM (lbs.)	Medicine Ball Toss (cm)	Long Jump (cm)	Right leg wallsit (sec)	Left leg wallsit (sec)	Push-ups (reps)	VO2max (mL/kg/min)
	Mean ± SD		36.6 ± 7.5	166.8 ± 60.2	94.2 ± 25.6	184.4 ± 49.0	261.3 ± 52.3	159. 1 ± 25.4	73.7 ± 43.9	69.5 ± 41.6	24.2 ± 12.1	42.9 ± 7.4
Body fat %	27.0 ± 9.4	Correlation Coefficient	-0.215	-.418*	-0.447*	-0.230	-0.119	-0.414*	-0.378*	-0.322*	-0.463*	-0.675*
		p-value	0.108	0.001	<0.001	0.085	0.377	0.001	0.004	0.016	<0.001	<0.001
Muscle mass %	39.9 ± 5.9	Correlation Coefficient	0.212	0.419*	0.471*	0.298*	0.246	0.512*	0.334*	0.270*	0.422**	0.596*
		p-value	0.114	0.001	<0.001	0.025	0.065	<0.001	0.012	0.044	0.001	<0.001
BMI (kg/m^2)	24.9 ± 3.9	Correlation Coefficient	-0.122	-0.552*	-0.070	0.029	0.036	-0.299*	-0.432*	-0.392*	-0.397*	-0.581*
		p-value	0.366	<0.001	0.606	0.830	0.791	0.024	<0.001	0.003	0.002	<0.001
Total body BMD (g/cm^2)	1.23 ± 0.10	Correlation Coefficient	0.134	0.144	0.482*	0.444*	0.372*	0.286*	-0.198	-0.193	0.332*	0.046
		p-value	0.342	0.308	<0.001	0.001	0.007	0.040	0.163	0.175	0.016	0.758
Femur neck BMD (g/cm^2)	1.03 ± 0.11	Correlation Coefficient	0.008	0.211	0.436*	0.457*	0.327*	0.261	-0.252	-0.247	0.366**	0.051
		p-value	0.953	0.133	0.001	0.001	0.018	0.062	0.074	0.080	0.008	0.729
L2-L4 BMD (g/cm^2)	1.26 ± 0.14	Correlation Coefficient	0.192	0.025	0.266	0.376*	0.374*	0.217	-0.317*	-0.223	0.106	-0.068
		p-value	0.172	0.861	0.057	0.006	0.006	0.122	0.023	0.116	0.453	0.645
1/3rd radius BMD (g/cm^2)	0.709 ± 0.05	Correlation Coefficient	-0.017	-0.108	0.259	0.344*	0.150	0.101	-0.230	-0.283*	0.106	-0.301*
		p-value	0.906	0.447	0.064	0.013	0.289	0.477	0.105	0.044	0.455	0.038
Bodyweight (kg)	69.3 ± 11.1	Correlation Coefficient	-0.136	-0.482*	0.102	0.121	0.344*	-0.129	-0.321*	-0.248	-0.303*	-0.484*
		p-value	0.314	<0.001	0.448	0.369	0.009	0.340	0.016	0.065	0.022	<0.001
Height (cm)	166.4 ± 6.6	Correlation Coefficient	0.051	-0.04	0.313*	0.213	0.526*	0.262*	0.102	0.166	0.109	0.028
		p-value	0.705	0.767	0.018	0.112	<.001	0.049	0.454	0.222	0.418	0.842
2023 average daily step count	8944.3 ± 2773.6	Correlation Coefficient	-0.045	0.181	0.412*	0.291	0.535*	0.286	0.409*	0.426*	0.427*	0.328
		p-value	0.792	0.284	0.011	0.08	<0.001	0.086	0.013	0.010	0.008	0.062
2023 average daily physical activity minutes	54.3 ± 30.2	Correlation Coefficient	-0.232	-0.059	0.276	0.202	0.440*	0.039	0.215	0.346	0.278	0.087
		p-value	0.265	0.779	0.181	0.332	0.028	0.855	0.314	0.097	0.179	0.693

Note: Spearman *rho* correlation analysis examining the relationship between *i)* body fat percentage and physical fitness test results, *ii)* muscle mass percentage and physical fitness rest results, *iii)* daily activity habits. BMD – bone mineral density, BMI – body mass index. Note that due to limitation of smartwatch use, daily physical activity n = 25 and daily step count n = 37. *Significant difference <0.05 (2-tailed)

Reproductive Health

Two-sided t-tests yielded parity status as a predictor for muscular power and strength, results are outlined in Table 5 (significant findings only) (see table Appendix B, SDC 1, physical fitness results by occupation, parity status, hormone birth control use, menstrual cycle length and frequency). The relationships between the covariates age and body fat % with parity status violated assumption checks for the ANCOVA analysis, therefore adjusted analyses were not performed. To note, having given birth within the last year (n = 5) was not related to physical fitness performance.

Table 5. A comparison of physical fitness test results between nulliparous and parous first responders and healthcare providers.

Fitness Metric	Nulliparous (n = 27)	Parous (n = 30)	Significance
Long Jump (cm)	167.4 ± 26.8	151.6 ± 21.9	0.017*
4RM Back Squat (R%)	133.0 ± 35.8	113.3 ± 28.3	0.024*
4RM Bench Press (R%)	68.3 ± 21.1	57.9 ± 13.7	0.029*

Note: T-tests (2-sided) were used to compare means of physical fitness test results of nulliparous and parous participants. RM = repetition maximum, R% = bodyweight / absolute weight lifted in RM.*Significance set to <0.05.

A normal (21-35 days) and regular menstrual cycle length for the last 12 months was reported by 50.9% of participants and was not a predictor of physical fitness performance. To note, almost half (48.2%) of participants reported using an app or calendar to track menstrual cycle symptoms. Hormone birth control use was reported by 52.6% of participants with no relationship with physical fitness performance.

DISCUSSION

To our knowledge, this study is the first comprehensive investigation into reproductive health, MSKi, and body composition as predictors of physical fitness in female first-responders and HCP in Canada. Supporting our hypothesis, this present study contributes that occupation, body composition, previous MSKi and a history of childbirth influence physical fitness in female individuals employed in arduous occupations.

Anthropometrics

Our findings indicate that higher bodyweight is correlated with decreased aerobic capacity, upper body power, and full body muscular endurance in both occupational groups. Furthermore, BMI, body fat percentage, skeletal muscle mass percentage, and BMD were also related to physical fitness performance. These results are consistent with current literature comparing body composition of servicewomen with military task performance and fitness testing. Research linking decreased aerobic capacity, as well as poorer upper- and lower-body strength, with higher relative body fat percentage and lower muscle mass is currently used to guide the body composition standards of the United States Marine Corps.(20, 21) Similar to what is observed in the elite female warfighters,(22) our data indicate that higher BMD is associated with increased physical performance. The literature describing the relationship between body composition and fitness of female first-responders and HCP in Canada is limited. Our study therefore confirms the importance of increased skeletal muscle mass, decreased body fat percentage, and decreased bodyweight in females working in arduous occupations within Canada.

Reproductive health

While no significant differences were observed in body weight, body composition or BMD between parous and nulliparous groups, parity status was related to fitness performance.

Nulliparous participants achieved better results in a number of the tests conducted in this present study, supporting our hypothesis. For example, participants in this present study who had not given birth previous were able to jump significantly further compared to the parous group (167.4cm ± 26.8 vs. 151.6± 21.6, p = 0.017). Given that childbirth results in significant structural changes to the pelvic floor, increasing the risk of urinary incontinence and pelvic floor dysfunction, the parous group may avoid high-impact exercises (i.e., jumping) in their training programs or chosen fitness regime.(23) Jump performance could also be influenced by the higher rate of foot injuries reported by the parous individuals in our sample compared to the nulliparous group (p = 0.027). This body region has previously been identified as more vulnerable in parous individuals. A recent study by our group/team utilizing an online questionnaire collected information from 748 female members of the Canadian Armed Forces, concluded that participants with a history of childbirth were more likely to have experienced a foot RSI (parous = 39.3% vs. nulliparous = 24.1%, aOR: 1.79, CI: 1.24 ; 2.59) during their career.(5) The higher risk of injury at this body region is likely due to increases in body mass and endocrine system responses to pregnancy resulting in anatomical changes in the foot (i.e., increased length, width, and volume).(24-27) As body mass may be contributing to injuries in the foot and body composition was related to physical performance, these factors may be interacting to impair lower body power.

The difference in jump performance may also relate to lower body strength, as demonstrated by the back squat in our protocol, jump ability was correlated with back squat strength (*rho* = 0.524, p > 0.001).(28) While heavy lifting during pregnancy has been discouraged previously, newly published findings contradicts this theory. Prevett *et al.*, (2023) demonstrate that heavy resistance training throughout pregnancy and postpartum, lifting ≥ 80% of one-repetition maximum, during pregnancy can be safe.(29) The aforementioned study also found that maintaining pre-pregnancy training levels until delivery may reduce reproductive complications. Presently, it is common practice to decrease physical training load and volume during pregnancy and the postpartum period. The decline or cessation of heavy resistance training might place parous individuals at a disadvantage compared to their nulliparous peers who continue to maintain strength adaptations. This theory could also explain the significantly higher bench press performance in the nulliparous group. Physical training should target this discrepancy as upper body strength can be important for the safety of first responders and HCPs during a number of occupation related tasks, such as equipment handling, lifting patients, or if required to restrain uncooperative individuals. Parity status, expanding beyond the postpartum period, as a predictor for physical fitness had not been explored previously in Canadian first-responders or HCPs. Factors such as parental leave policies, professional physical training support, type of birth, or number of children could be contributing to the diminished fitness performance. Our findings justify initiatives and investigations aimed specifically at supporting females who bear children and choose to return to physically demanding careers.

Physical activity and exercise behaviours

Team sport participation is a valuable platform for first-responders to learn occupation related skills and ideals, encourage social connection, while improving physical fitness.(30) Research conducted on Canadian military personnel indicate sport participation can also improve mental health status, a benefit that must be considered when supporting a population with high rates of suicide.(31) Given that a recent systematic review identified 8.9%-74.2% of HCP experience symptoms of depression, with females being at greater risk,(32) the combined mental and physical health benefits of sport participation make this an appropriate exercise modality for both first-responders and HCP. Our findings indicate first-responders were more likely to have participated in team sports within the last year than the HCP group. Participation in team sports was related to better standing long jump performance, and lower jump distance was associated with injury prevalence. HCP in our sample were more drawn to virtual fitness classes. Limited comparative data for fitness benefits yielded from virtual compared to in-person physical training classes exist, with only one study identified when reviewing the literature. The aforementioned publication compared the effects of a 10-week high intensity interval training program for obese and overweight female individuals, delivered in-person (n = 9) and virtually (n = 11) demonstrated better fitness results in the onsite group.(33) Though physical and physiological adaptations can certainly be accrued from virtual class participation,(33) other forms of exercise (*i.e.*, team sports, follow a PT program, or attend in-person fitness classes) appear to yield greater physical fitness benefits. Our results showing better flexibility, stronger lower body, and higher upper body strength indicate subscribing to a physical training program created by a fitness professional may be the optimal choice for achieving higher levels of fitness.

Physical training created and administered by qualified professionals improves injury rehabilitation results,(34) and the value of trainer qualifications on physical fitness outcomes has been demonstrated previously.(35) Roos *et al.*, (2015) found that ten weeks of physical training designed and administered by a coach with a degree in physical education, compared to a programming by army physical training instructors, yields superior strength, balance, and aerobic endurance.(35) Seemingly, participants in our sample seek professional support after sustaining injury. While 44.6% of the participants in our study currently follow a training program made by a fitness professional (e.g., Strength and conditioning coach, kinesiologist, physical trainer), 96.0% of those in this group had sustained an RSI previously ($p = 0.004$). This compares to 44.4% of participants who attend fitness classes in person (e.g., spin, yoga, high-intensity interval training) having RSI history ($p= 0.021$). As healthcare professionals and first-responders rely on subject matter experts and often collaborate with specialists, it is possible that individuals in these occupations apply a similar approach to their own health.

For example, they may opt to utilize individualized professional support for physical training following an injury to avoid exacerbating previous injury.

Based on our findings and the current literature, investigations and interventions involving the effectiveness of exercise and physical training should consider delivery method, qualifications of the individual administering the program, and differentiate between team or non-team sports. While the focus of this study was to explore factors contributing to physical fitness in females employed as first-responders or in healthcare, psychological strain on individuals in these occupations must be acknowledged. Future research examining the impact of various physical training modality participation on burnout and other aspects mental health, in addition to investigations of the relationship between psychological health and physical fitness would be helpful for guiding health initiatives for these individuals.

Limitations

This analytical cross-sectional study combines physiological testing with a retrospective component (*i.e.,* questionnaire). The risk of recall bias is increased due to the injury data being gathered by self-report questionnaire. Injury data collected via self-report has been validated in arduous occupations, though underreporting via this method has also been demonstrated.(36) While the sample size included in this present study was beyond the initial power calculation performed for the project, the statistical analyses used were limited based on the number of participants in some categories. Thus, where small sample sizes were compared, findings should be considered preliminary. A larger sample would be especially advantageous for the injury and occupation comparisons, as it would enable the inclusion of covariates and reduce the risk of chance relationships. The effect of age could be especially insightful to assess, as peak strength in females is seen between 30-39 years of age, runners who plan to return to sport after pregnancy have no statistical decrease in performance 1-3 years post pregnancy and over half have significant performance improvements, and there is a considerable literature gap examining the relationship of reproductive health status through the female lifespan.[32,37,38] A larger sample would also permit for a more robust assessment of reproductive health variables, such as differentiating between oligomenorrhea and amenorrhea or performing post-partum and parity status comparisons. To note, a requirement for participation in this present study was the ability to attend testing at University of Ottawa, participants were all members of municipal and provincial organizations based in the National Capital Region of Canada. The pregnancy policies, maternity benefits, and return-to-work requirements vary between these organizations limiting job-specific recommendations from our findings. Another limitation may also be the lack of smartwatch standardization. While the data collected by smartwatches can provide valuable insight into daily physical activity minutes or step counts, validity between devices varies. The physical activity data included in this study should therefore be viewed as approximations. This study was not designed to determine causality, further investigation is needed to understand the relationships observed.

CONCLUSION

MSKi are prevalent among females in arduous occupations overall but were not overwhelmingly predictive of physical fitness. Conversely, a history of childbirth, body composition, and exercise behaviours were related to physical fitness in law enforcement, firefighting, paramedicine, and healthcare personnel. The minimal interaction between MSKi history and physical fitness may be due, in part, to physical training practices. Thus, interventions for females employed in arduous roles should consider exercise type and delivery method based on specific occupation category. Physical fitness programs aimed at supporting parous first-responders or healthcare providers should emphasize lower body power, lower body strength, and upper body strength. Further, the needs analysis for physical training and physical therapy program design should be informed by occupation, reproductive health factors, injury history, and body composition.

CONFLICT OF INTEREST

The authors do not have conflict of interest(s) to disclose. We declare the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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SUPPLEMENTAL DIGITAL CONTENT

SDC 1.

Appendix A. Anthropometric measures and physical fitness assessment protocol

i) **Body composition:**

Participants were asked to further remove any metal objects on their person (i.e., watch, rings, other jewelry). Individuals then stood on the InBody® (USA) bioelectrical impedance analyzer (BIA), hold the body composition analyzer arms. The BIA device directed the person on how long they needed to remain standing or if they needed to reposition. Body weight was also obtained during this test. This test was performed fasted (8 hours nothing to eat or drink).

ii) **Bone mineral density:**

UltraScan650™ measurement: The length of the right forearm was measured. The ulna position locator (UPL) was be placed (using its pair of pins) into a pair of holes in the base of the unit, located along the scale at the same value as the ulna length. A hand positioning locator (HPL) must be placed on the UPL, so that the patient can maintain a consistent position and orientation of the hand/forearm. The sensors of the device and the forearm of the participant was sprayed with 70% isopropyl alcohol. The participant rested their elbow on a pad located on the right-side of the device. The forearm of the participant was secured for the scan. The scan was repeated 3-5 times as needed. The scan was repeated 15 times for participants selected for the reproducibility component of the study.

DXA measurement: The DXA device used was GE Lunar Prodigy (GE Healthcare Lunar, Madison, MI, USA). Participants wore fitted clothing and removed all metals from their person. Participants were fasted (nothing to eat or drink for a minimum of 8 hours prior to attending study) and were asked not to engage in strenuous physical activity in the last 24hrs. Four scans took place: i) Full body, participants lay on their back on the device, ii) Right forearm, participants sat in an upright position beside the DXA with their arm on the device and secured to a board by two straps, iii) Lumbar spine, participants lay in a supine position with their legs place on a positioner box secured by straps at the knees and ankles, iv) Femur, participants lay in a supine position with their legs place on a positioner box secured by straps at the knees and ankles. Participants were positioned by a member of the research team. The DXA operator received DXA training from a representative of GE Healthcare.

After the bone mineral density test, participants were permitted to eat and drink.

A standardized warm-up was performed. The standardized warm-up started general and ended with movements specific to the test protocol. The general phase (2 min): jogging, high-knees, high-heels, walking lunges. General to specific phase (4 min): static and dynamic stretching and activation. Specific phase (4 min): body weight/low weight repetitions of the movements included in the test. During this phase, movement coaching occurred for the maximal strength tests.

iii) **Flexibility**: The sit-and-reach test box was be placed against a wall. With their shoes off, participants sat with the bottom of their feet against the box and their legs extended. With one hand placed over the other (palm side down), their arms outstretched parallel to the floor and directed to their toes, participants leaned forward in a slow and steady movement to briefly hold and achieve the greatest distance. Participants performed 3 attempts with a 30-second rest interval between each repetition.

iv) **Muscular power**: standing long jump and medicine ball explosive power tests was performed to assess lower- or upper-body power. For the jump tests, each subject stood at the starting position with their legs parallel and feet shoulder-width apart. Participants were instructed to bend at the knees and bring the arms behind the body. Then, with a powerful drive, they extended their legs, thrust their arms forward and jump as far horizontally as possible (standing long jump). For the standing long jump, individuals were asked to 'hold' the landing while the distance was measured from the start line to the back of the closest heel.

For the medicine ball explosive power test, subjects sat on a chair placed against a wall, holding a medicine ball. A tape measure was placed on the ground starting at the front end of the chair of the subject and stretched out to a distance of 15 m. With their backs against the chair for support and their feet flat on the ground, participants were advised to 'push' a 3 kg medicine ball, originally held at the level of the centre of their chest, away as far as possible using a motion similar to a basketball chest pass.

The best of three attempts was recorded for each power test and a 1 min rest interval allowed between repetitions.

v) **Strength**: Four repetition maximum (RM) were performed in bench press and back squat exercises. Participants had 7 attempts for each exercise with 3-5min interval between them. Weight progression recommendations were 5 kg for bench press, and 10 kg for the back squat however participants could request different progression weights. Two or three spotters followed all the strength tests to ensure safety of the participant (one on each side of the bar and one behind during the squats). 5-10 minutes rest between the back squat and bench press tests were provided to the participants.

vi) **Endurance strength**: Push-up test (maximum number of repetitions), Biering-Sorenson test (time to exhaustion), and single leg wall sit (time for each leg with 1-min interval between legs) to assess muscle endurance in both upper- and lower-body. There was a 20-minute interval between endurance strength tests and the aerobic fitness test.

vii) **Aerobic fitness**: A graded treadmill exercise test (GXT) based on Modified Balke protocol and indirect calorimetry individual's maximal aerobic capacity (VO_{2max}) was applied to measure the gold-standard maximal oxygen uptake (VO_{2max}). Expired gases were collected and analyzed using the wearable and portable metabolic system (K5, COSMED s.r.l., Rome, Italy). A Hans Rudolph (Hans Rudolph Inc, Kansas, USA) facemask and head support will be fitted on the participant and attached to the K5 unit. A Polar Wear Link and coded transmitter (Polar Electro Canada Inc, Lachine, QC) to monitor heart rate was fitted and secured around the chest beneath the participant's nipple line, next to the skin. The Polar H800 receiver (watch) was be secured to the treadmill and monitored by the assessors.

Prior to the start of the test, participants had their resting HR measured and participants were permitted to familiarize themselves with treadmill running by warming up for a period of 5 minutes. Age-predicted heart rate reserve is determined using the Karvonen method for calculating reserve: HR_{max}-HR_{rest}. While there is debate regarding accurate determination of age-predicted HRmax, when combined with $HR_{reserve}$ it can be useful in establishing an evidence- based running speed for the GXT. HR_{max} is determined using the following equation: 208-0.7*age.

Warm-up: Participants did not wear to the breathing apparatus (i.e., facemask and head support) for the warm-up, but did wear the Polar heart rate (HR) monitor. Participants started running on the treadmill at a speed of 4.0 miles per hour (mph) and speed gradually increased until they reach a comfortable warm-up speed between 5.0 – 7.0 mph. The treadmill speed for the test was based on the speed at which the participant attained a HR greater than 75% of their age-predicted heart rate reserve during the warm-up. Immediately after the determination of initial running speed for the test, the participant was be fitted to the breathing apparatus (i.e., facemask and head support). Participants stood for 3-5 minute in a standing position to collect baseline metabolic values while allowing one to get accustomed to wearing and breathing through the mask. This standing period allowed us to ensure the values being collected were valid prior to the actual test.

Test: Using the speed determined during the warm-up, the first 2 min of the treadmill test were completed at a grade of 0%. After that, the treadmill incline increased by 2% every 2 min until a respiratory exchange ratio (RER) of 1.0 was achieved. When an RER value of 1.0 was achieved, the treadmill incline was be increased by 1% every minute until volitional fatigue, at which time the test was be terminated. At the end of each 2-min test increment, up to when an RER value of 1.0 was achieved, the participants provided a rating of their perceived exertion using a Borg Scale, as rate of perceived exertion (RPE) has been found to be a valuable and reliable indicator in monitoring an individual's exercise tolerance. RPE correlates highly with measured exercise HR and were developed to allow the exerciser to subjectively rate their feelings during exercise.

Every effort was made to conduct the test in a manner to minimize discomfort and risk. The participant was notified that they may stop the test at any time. Criteria for the termination of the VO_{2max} test included any of the following:

• onset of angina (chest pain) or angina-like symptoms

• signs of poor perfusion – light headedness, confusion, pallor (pale appearance to the skin), cyanosis (bluish discoloration); ataxia (failure of muscular coordination), nausea, or cold and clammy skin

• participant requested to stop

• volitional fatigue

• physical or verbal manifestations of severe fatigue

• failure of testing equipment

• shortness of breath, wheezing, leg cramps

• failure of HR to increase with increased exercise intensity

Any participant that displays one or a combination of any of the previously mentioned criteria for test termination was to be referred to the appropriate medical authorities on-site. Various objective and subjective indicators are useful to confirm that maximal effort has been elicited during the GXT. The following indicators were be used to confirm VO_{2max}:

• failure of HR to increase with further increases in exercise intensity

• a plateau in oxygen uptake (or failure to increase oxygen uptake by 150 ml/min) with increased workload

• an RER greater than 1.15

• an RPE of more than 17 (6 to 20 scale)

SDC 2.

Appendix B: Physical fitness results by occupation, parity status, hormone birth control use, menstrual cycle length and frequency

	Occupation			Parity Status			Hormone Birth Control			Menstrual cycle length and frequency		
Fitness Metric	First responders (n = 19)	HCP (n = 38)	Sig.	Nulliparous (n = 27)	Parous (n = 30)	Sig.	Yes % (n = 30)	No % (n = 27)	Sig.	Regular (n = 29)	Irregular (n = 28)	Sig.
Sit-and-Reach (cm)	36.9± 6.7	36.5 ± 7.9	0.860	37.8 ± 7.4	35.6 ± 7.5	0.273	37.5 ± 7.5	35.8 ± 7.5	0.405	35.8 ± 7.8	37.5 ± 7.2	0.389
Long Jump (cm)	167.5 ± 22.8	154.9 ± 25.9	0.066	167.4 ± 26.8	151.6 ± 21.9	0.017*	164.6 ± 25.8	153.0 ± 23.9	0.085	160.8 ± 25.6	157.3 ± 25.5	0.616
Medicine Ball Toss (cm)	294.7 ± 45.6	244.6 ± 48.7	<0.001*	265.2 ± 46.1	257.7 ± 59.1	0.599	276.9 ± 51.1	253.9 ± 54.9	0.321	262.1 ± 50.6	262.1 ± 56.2	0.907
4RM Back Squat (R%)	131.8 ± 41.6	118.1 ± 27.7	0.142	133.0 ± 35.8	113.3 ± 28.3	0.024*	124.2% ± 30.4%	120.9% ± 36.7%	0.715	130.2% ± 28.1%	114.8% ± 36.7%	0.080
4RM Back Squat (lbs.)	172.63 ± 36.8	207.8 ± 61.8	0.009*	194.9 ± 50.9	174.8 ± 46.1	0.123	189.3 ± 42.4	178.8 ± 55.7	0.423	191.0 ± 44.0	177.4 ± 53.7	0.299
4RM Bench Press (R%)	70.0 ± 20.2	59.2 ± 16.3	0.054	68.3 ± 21.1	57.9 ± 13.7	0.029*	61.9% ± 17.4%	63.8% ± 19.4%	0.703	66.5% ± 17.1%	59.0% ± 18.8%	0.119
4RM Bench Press (lbs.)	110.0 ± 28.3	86.3 ± 20.3	0.003*	99.8 ± 29.7	89.2 ± 20.6	0.118	94.7 ± 25.7	93.7 ± 26.1	0.889	96.9 ± 22.6	91.4 ± 28.6	0.426
Biering-Sorenson (sec)	153. 2 ± 53.0	173.6 ± 63.1	0.206	165.7 ± 56.7	167.8 ± 64.1	0.893	168.4 ± 53.1	165.1 ± 68.3	0.841	174.1 ± 61.0	159.3 ± 59.5	0.357
Single-leg Wall Sit (Rt)	78.2 ± 54.9	71.6 ± 38.2	0.652	73.2 ± 46.6	74.2 ± 42.1	0.934	67.1± 42.0	81.4 ± 45.5	0.228	82.0 ± 39.9	64.9± 46.8	0.145
Single-leg Wall Sit (L)	68.9 ± 44.2	70.8 ± 36.6	0.869	64.8 ± 31.7	73.6 ± 48.8	0.432	68.6± 49.5	70.5 ± 31.1	0.869	79.6 ± 44.2	58.7 ± 36.4	0.059
Push-ups (reps)	27.7 ± 13.6	22.4 ± 11.0	0.150	26.5 ± 13.1	22.1 ± 11	0.178	25.0 ± 11.8	23.3 ± 12.6	0.585	26.8 ± 11.3	21.5 ± 12.5	0.094
VO_{2max}(mL/kg/min)	43.6 ± 8.5	42.6 ± 7.0	0.687	44.6 ± 7.0	41.3± 7.6	0.113	42.6 ± 7.3	43.2 ± 7.8	0.785	43.6 ± 6.9	42.2 ± 8.0	0.496

Note: T-tests were used to compare means of physical fitness test results of first responders and healthcare providers, parity status (nulliparous [n = 27] vs. parous [n = 30]), who do (n = 30) and do not (n = 27) use hormonal birth control, and regular (n = 29) or irregular (n = 28) menstrual cycle. HCP = healthcare provider, BC = birth control, RSI = repetitive strain injury. RM = repetition maximum, R% = (absolute weight lifted in 4RM relative to bodyweight), Rt = right, L = left, reps = repetitions. *Significant two-sided p-value <0.05.

SDC 3.

Appendix C. Musculoskeletal injuries stratified by female reproductive health factors and occupation.

Injury	Parity Status			Hormone Birth Control			Menstrual Cycle			Occupation		
	Nulliparous % (n = 33)	Parous % (n = 30)	Significance	Yes % (n = 30)	No % (n = 27)	Significance	Irregular % (n = 29)	Regular % (n = 28)	Significance	FR % (n = 19)	HCP % (n = 38)	Significance
Acute	74.1	80.0	0.594	70.0	85.2	0.172	71.4	82.8	0.308	78.9	76.3	0.823
RSI	74.1	83.3	0.392	76.7	81.5	0.656	75.0	82.8	0.473	94.7	71.1	0.045^
Head, neck, shoulder	44.4	53.3	0.503	43.3	55.6	0.357	42.9	55.2	0.352	68.4	39.5	0.039*
Upper extremity	37.0	56.7	0.138	36.7	59.3	0.088	39.3	55.2	0.230	57.9	42.1	0.260
Back	44.4	46.7	0.866	40.0	51.9	0.370	42.9	48.3	0.681	78.9	28.9	<0.001*
LPHC	51.9	50.0	0.889	43.3	59.3	0.230	53.6	48.3	0.689	84.2	34.2	<0.001*
Lower extremity	63.0	73.3	0.400	63.3	74.1	0.384	64.3	72.4	0.509	68.4	68.4	1.000
Pelvis	7.4	10.0	1.000^	10.0	7.4	1.000^	10.7	6.9	0.670^	15.8	5.3	0.321
Thorax/Ribs	3.7	3.3	1.000^	3.3	3.7	1.000^	3.6	3.4	1.000^	5.3	2.6	1.000^
Breast	0.0	10.0	0.239^	3.3	7.4	0.599^	0.0	10.3	0.237^	15.8	0.0	0.033^*
Abdomen	3.7	6.7	1.000^	6.7	3.7	1.000^	0.0	10.3	0.237^	15.8	0.0	0.033^*
Lower back	40.7	40.0	0.955	40.0	40.7	0.955	42.9	37.9	0.705	78.9	21.1	<0.001*
Upper back	14.8	20.0	0.734^	13.3	22.2	0.492^	14.3	20.7	0.730^	21.1	15.8	0.717^
Toes	0.0	13.3	0.114^	6.7	7.4	1.000^	3.6	10.3	0.611^	5.3	7.9	1.000^
Foot	3.7	26.7	**0.027*^**	13.3	18.5	0.722^	7.1	24.1	0.144^	21.1	13.2	0.463^
Ankle	25.9	43.3	0.169	33.3	37.0	0.770	28.6	41.1	0.311	42.1	31.6	0.432
Lower leg	10.0	14.8	0.697	6.7	18.5	0.238^	14.3	10.3	0.706^	10.5	13.2	1.000
Knee	33.3	43.3	0.439	36.7	40.7	0.752	39.3	37.9	0.916	57.9	28.9	0.034*
Thigh	7.4	3.3	0.599	6.7	3.7	1.000^	7.1	3.4	0.611^	15.8	0.0	0.033^*
Hip	18.5	30.0	0.315	13.3	37.0	0.038*	21.4	27.6	0.589	42.1	15.8	0.049^*
Fingers	11.1	13.3	1.000	6.7	18.5	0.238	14.3	10.3	0.706	26.3	5.3	0.035^*
Thumb	7.4	23.2	0.149^	16.7	14.8	1.000^	10.7	20.7	0.470^	10.5	18.4	0.703^
Hand	3.7	10.0	0.613^	0.0	14.8	0.044*	7.1	6.9	1.000^	10.5	5.3	0.594^

Wrist	22.2	16.7	0.596	23.3	14.8	0.416	25.0	13.8	0.284	10.5	23.7	0.304^
Lower arm	11.1	6.7	0.660^	3.3	14.8	0.179^	3.6	13.8	0.352^	10.5	7.9	1.000^
Elbow	18.5	13.3	0.722^	20.0	11.1	0.476^	21.4	10.3	0.297^	26.3	10.5	0.143^
Upper arm	0.0	6.7	0.429^	0.0	7.4	0.220^	0.0	6.9	0.491^	5.3	2.6	1.000^
Shoulder	29.6	43.3	0.284	26.7	48.1	0.093	32.1	41.4	0.470	52.6	28.9	0.081
Neck	14.8	23.3	0.416	23.3	14.8	0.416	14.3	24.1	0.346	42.1	7.9	0.004^
Head	14.8	16.7	1.000^	13.3	18.5	0.722^	17.9	13.8	0.730^	26.3	10.5	0.143^

Note: Chi-square analysis of musculoskeletal injuries by parity status (nulliparous [n = 27] vs. parous [n = 30]), participants who do (n = 30) and do not (n = 27) use hormonal birth control, regular (n = 29) and irregular (n = 28) menstrual cycle, and occupation (first responder [n = 19] and healthcare provider [n = 38]). BC = birth control, RSI = repetitive strain injury, FR = first=responder, HCP = healthcare provider. ^ Fisher's Exact (2-sided). *Significant difference p-value <0.05.

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Appendix D. Physical fitness results by musculoskeletal injury stratified by body region.

	Head, Neck, Shoulder Complex			Upper Extremity			Back			Lumbopelvic Hip Complex			Lower Extremity		
Fitness Metric	Yes % (n =28)	No % (n = 29)	P-value	Yes % (n = 27)	No % (n = 39)	P-value	Yes % (n = 26)	No % (n = 31)	P-value	Yes % (n = 29)	No % (n = 28)	P-value	Yes % (n = 39)	No % (n = 18)	P-value
Sit-and-Reach (cm)	38.1 ±7.9	35.2±6.9	0.143	36.0 ±8.6	37.2 ±6.4	0.558	38.2 ±6.7	35.4 ±8.0	0.164	38.5 ± 6.9	34.7 ±7.6	0.056	36.8 ±7.4	36.4 ± 8.0	0.841
Long Jump (cm)	162.1±25.0	156.2 ±25.9	0.382	156.9 ±22.9	161.6 ±27.7	0.491	159.6 ±25.2	158.6 ±26.0	0.882	157.6 ±27.3	160.6 ±23.7	0.668	156.6 ±28.0	164.4 ± 18.1	0.285
Medicine Ball Toss (cm)	270.1 ±57.6	252.8 ±47.5	0.219	269.2 ±58.6	254.1 ±47.1	0.286	286.2 ±46.9	240.4 ±49.1	<0.001*	274.1 ±56.1	248.0 ±46.7	0.062	260.8 ±55.2	262.4 ±49.3	0.917
4RM Back Squat (R%)	118.3 ±30.4	126.8 ±35.8	0.340	118.4% ±29.0%	126.5% ±36.8%	0.367	120.9% ±38.8%	124.1% ±28.4%	0.732	116.8% ±33.9%	128.7% ±32.1%	0.180	118.0%±30.9%	132.7%±36.8%	0.121
4RM Back Squat (lbs.)	185.0 ±51.7	183.7 ±46.9	0.923	186.11 ±48.2	182.8 ±50.5	0.800	189.5 ± 59.4	180.0 ±38.7	0.486	182.1 ±54.0	186.7 ±44.1	0.724	176.7 ±48.3	201.0 ±47.7	0.081
4RM Bench Press (R%)	63.4 ±18.4	62.3 ±18.4	0.822	61.2% ±16.3%	64.3% ±19.9%	0.535	61.4% ±17.7%	64.0% ±18.9%	0.593	61.7% ±18.1%	64.0% ±18.6%	0.629	61.5% ±17.2%	65.6% ±20.5%	0.436
4RM Bench Press (lbs.)	98.2 ±26.4	90.3 ±24.7	0.250	95.4 ±21.8	93.2 ±29.0	0.749	96.2 ±26.3	92.6 ±25.4	0.605	95.9 ±27.8	92.5 ±23.5	0.625	98.9 ±26.4	92.1 ±25.3	0.354
Biering-Sorenson (sec)	163.8 ±68.1	169.8 ±52.5	0.711	161.5 ±69.3	171.6 ±51.4	0.532	152.3 ±52.2	179.0 ±64.5	0.096	151.3 ±48.9	182.9 ±67.1	0.047*	172.7 ±61.2	154.2 ±57.6	0.286
Single-leg Wall Sit (Rt)	67.2 ±36.5	79.9 ±49.6	0.282	67.7 ±38.2	79.0 ±48.2	0.338	83.0 ±51.1	66.3±36.3	0.160	77.0 ±35.5	70.5 ±51.3	0.580	69.7 ±32.3	82.3 ±61.9	0.319
Single-leg Wall Sit (L)	65.6 ±33.5	73.2 ±48.3	0.501	64.3 ±33.4	74.0 ±47.8	0.390	75.7 ±36.4	64.6 ±45.4	0.324	72.5 ±31.2	66.5 ±50.4	0.854	68.8 ±42.8	71.0 ±40.3	0.425
Push-ups (reps)	25.0 ±13.0	23.41 ±11.3	0.625	23.4 ±10.9	24.9 ±13.2	0.662	22.3 ±10.8	25.8 ±13.1	0.285	22.6 ±12.2	25.86 ±12.0	0.601	24.8 ±12.4	22.9 ±11.6	0.854
VO_{2max}(mL/kg/min)	41.1 ±7.0	44.5 ±7.5	0.094	41.1 ±7.4	44.3 ±7.3	0.118	41.3 ±7.4	44.0 ±7.4	0.191	42.1 ±7.2	43.6 ±7.7	0.684	42.6 ±6.5	43.5 ±9.2	0.601

Note: T-tests were used to compare means of physical fitness test results of who have and have not sustained musculoskeletal injuries at the head, neck, shoulder complex, upper extremity (fingers, thumb, hand, wrist, lower arm, elbow upper arm, shoulder), back (neck, upper back, low back), lumbopelvic hip complex (low back, pelvis, hip), lower extremity (hip, thigh, knee, lower leg, ankle, foot, toes). RM = repetition maximum, R% = (bodyweight / absolute weight lifted in RM), Rt = right, L = left, reps = repetitions. *Significant two-sided p-value <0.05

CHAPTER 6 PREAMBLE

The results from Chapters 3 and 5 identified conflicting relationships between parity status, MSKi, and physical fitness. In this chapter, the samples from both the CAF and non-military projects are combined to provide a better understanding of what may be contributing to the interactions between fitness, parity status, and MSKi history.

Chapter 6

Comparing Military and Non-Military Female Personnel

Study title**:** Are occupation, a history of childbirth, and musculoskeletal injury history related to physical fitness in females employed in military and non-military arduous careers?

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CHAPTER 6 SUMMARY INFOGRAPH

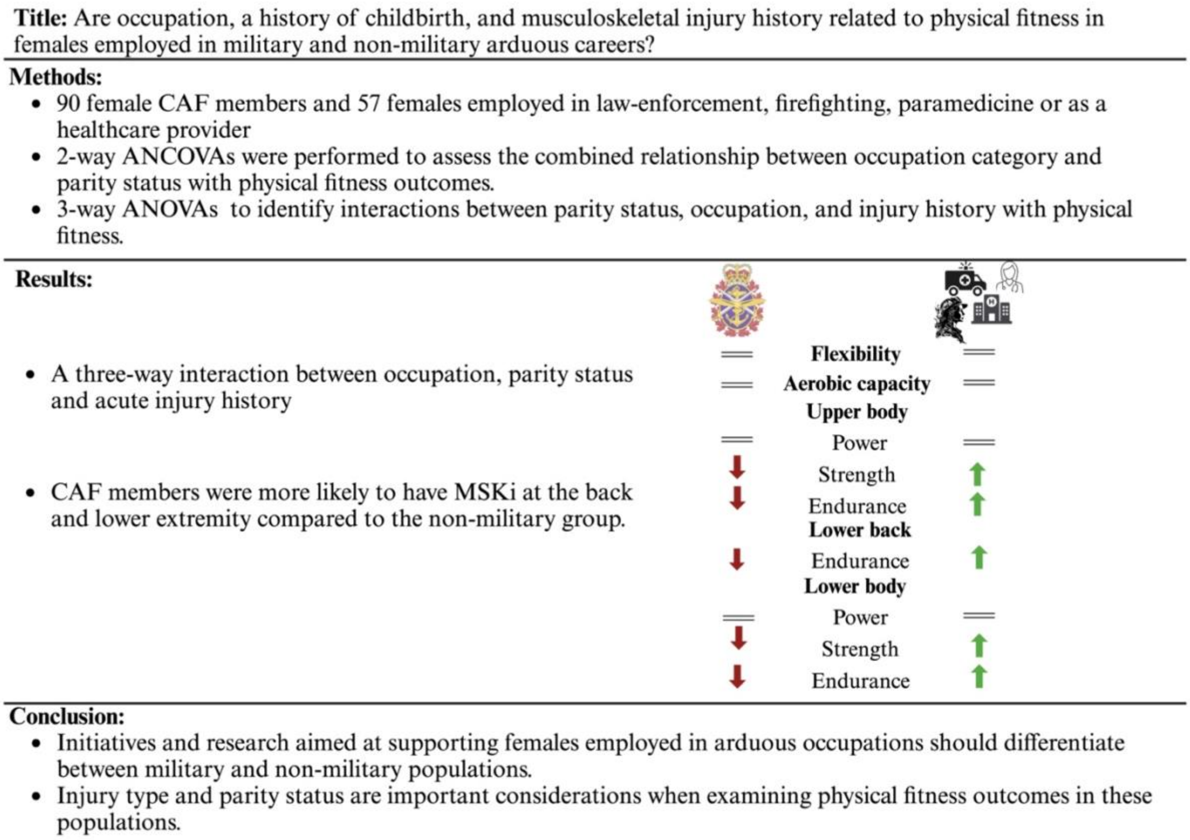

Figure 6.0 Visual summary of *Project 4"Are occupation, a history of childbirth, and musculoskeletal injury history related to physical fitness in females employed in military and non-military arduous careers?"*. ANCOVA = Analysis of covariance, RSI = repetitive strain injuries, RM = repetition maximum, MSKi = musculoskeletal injuries.

ABSTRACT

Background: Musculoskeletal injuries (MSKi) place a significant burden on female military service members, first responders (protective service personnel), and healthcare workers. Military and arduous occupations (non-military) populations are often grouped together in research, but direct comparison of physical fitness or common injuries of these groups has not been conducted on females in these roles. Further, the relationship between parity status, occupation, and injury history with physical fitness has not been explored in females employed in arduous occupations.

Methods: This study combined data from two independent projects that applied the same physical testing protocol and a similar health demographics questionnaire. Fifty-seven females employed as either a firefighter, paramedic, law enforcement officer, or healthcare provider and 90 female members of the Canadian Armed Forces (CAF) completed the following assessments: *i)* muscular power (standing long jump and medicine ball throw), *ii)* muscular strength (4 repetition maximum back squat and bench press), *iii)* muscular endurance (Biering Sorenson test, single-leg wall sit, and push-ups), *iv)* flexibility (sit-and-reach), and *v)* aerobic capacity (graded treadmill VO_{2max} test). Chi-square, Fisher's exact test, and likelihood ratios were used to compare MSKi history between occupation groups. Comparisons of physical fitness test results between occupation groups (military v. non-military) were first performed using independent t-tests. Univariate analysis of covariance (ANCOVA) were applied when occupation was significantly related to a physical fitness test result at the t-test. Significance was set to $p<0.05$.

Results: Female members of the CAF were more likely to sustain injuries involving the back (CAF 68.9% vs. NM 45.6%, [OR:2.56, CI:1.27-5.17, p =0.008]), hip (CAF 40.0% vs. NM 24.6% [OR: 2.41, CI:1.11-5.28, p = 0.026]), foot (CAF 33.3% vs. NM 15.8% [OR: 3.43, CI: 1.41-8.34, p = 0.007]), and lumbopelvic hip complex (CAF 73.3% vs. NM 50.9%, OR:2.94

CI:1.42-6.07, p = 0.004), while those employed in healthcare or as first responders were more likely to experience a thumb injury (CAF 3.3% vs. NM 15.8% [OR:0.223, CI:0.06-0.90, p = 0.036]). The NM group performed better in the bench press, back squat, Biering Sorenson test, single leg wall sit (both legs), and completed more push-ups than the military group.

Conclusions: The superior physical fitness in the NM group and increased likelihood of MSKi in the CAF participants suggest these groups are less comparable than traditionally thought. Initiatives and research to support females employed in arduous occupations should differentiate between military and non-military populations.

INTRODUCTION

Musculoskeletal injuries (MSKi) place a significant burden on female military service members, first responders (protective service personnel), and healthcare workers.[1-6] In the Canadian Armed Forces (CAF), females are more likely to release due to an MSKi than their male peers, and male healthcare workers demonstrate a lower relative risk for all injuries.[5,7] The number of females pursuing careers as military members, protective service personnel, and healthcare workers is increasing, but are vastly underrepresented in the literature. An important consideration as we address this knowledge gap is the increasing number of employees who continue careers after childbirth in Canada.[8]

A recent opinion article written by various experts in military medicine and pregnancy highlights the dearth of evidence surrounding fitness and exercise during pregnancy and postpartum in arduous occupations.[9] Jackson *et al.,* (2022) conclude that insufficient evidence is available to form best practice recommendations for the care of pregnant or postpartum elite-athletes or personnel in physically strenuous roles.[9] As initiatives aimed at supporting career longevity of females, it would be beneficial to identify if we can use research conducted on females working in military and non-military tactical or emergency response occupations interchangeably. Military and arduous occupations (non-military) populations are often grouped together in the literature due to the perceived similarity in job demands.[9,10] A direct comparison of physical fitness or injuries within these groups is not currently available in the literature. Thus, the purpose of this study is to compare *i)* physical fitness test results, and *ii)* MSKi history between females employed in military (CAF) and non-military arduous occupations (*e.g.,* law enforcement officer, firefighter, paramedic, healthcare provider [as defined by the Province of Ontario]). A secondary aim is to assess if parity status combined with occupation category is related to physical fitness or injury. We anticipate that the military members will achieve superior results for the physical fitness testing and sustain more MSKi, compared to the non-military group. We also hypothesize that parous military members will sustain more injuries and that nulliparous military members will perform better on the physical fitness assessments.

METHODS

This study combines data from two separate projects. The following descriptions were provided on the informed consent forms used for each study:

1) Military (testing occurred October-December 2021 at CFB Petawawa and University of Ottawa):

Aims: "…*Characterize Canadian Armed Forces members who are 'susceptible to' vs. 'protected against' musculoskeletal injuries through a battery of assessments…"*

Inclusion*: "i) being between the ages of 18 and 55 years, ii) being an active member of CAF, iii) being cleared to engage in maximal exercise (based on the Health Appraisal Questionnaire), and iv) providing informed consent to participate (in English or French)."*

2) Non-Military (testing occurred April-June, 2023 at the University of Ottawa:

Aims: "i*) characterize MSKi and physical fitness of female civilian first responders and health care workers, ii) examine if parity status (history of childbirth) is associated with physical fitness test results*."

Inclusion criteria*: "i) biological sex of female, ii) being between the ages of 18 and 55 years, iii) employed as a healthcare worker, as a firefighter, law enforcement officer, or paramedic, iv) being cleared to engage in maximal exercise (based on the pre-screening questionnaire), and v) providing informed consent to participate (in English or French)."*

With the exception of having institutional support by the CAF and Department of National Defence Canada for the military group (*i.e.*, recruitment materials on official social media pages, newsletters), recruiting methods for both projects were similar (e.g., social networks of the research team, 'snowball' recruiting). While the aims of these two projects differed, the same MSKi definitions were included as prompts on the self-report questionnaire:

iii) *"Repetitive Strain or Overuse Injuries - injuries to muscles, tendons or nerves caused by overuse or repeating the same movement over an extended period. For example, carpal tunnel syndrome, tennis elbow, plantar fasciitis, or tendonitis."*

iv) *"Acute Injuries – serious physical injuries, likely caused by a significant level of exertion or single incident of trauma, which were serious enough to require at least 24 hours off work after it to recover from. For example, a broken bone, a sprain."*

The physical fitness tests applied in both projects include:

i. Flexibility (sit-and-reach),

ii. Muscular power (long jump and medicine ball throw)

iii. Muscular strength (4 repetition maximum back squat and bench press)

iv. Muscular endurance (Biering-Sorenson test, single-leg wall sit, and push-ups),

v. Aerobic capacity (graded treadmill VO_{2max} test],

Anthropometric measures were also collected using the same devices:

i. Height was measured by a portable stadiometer (Seca, USA)

ii. Body weight and body fat % data were collected using the InBody® 570(USA) bioelectrical impedance analyzer (BIA).

Detailed descriptions of the protocols used for both the military and non-military studies can be found in the original articles from which this comparison was inspired (Edwards *et al.*, Submitted*;* Edwards *et al.*, Submitted)

The variables of interest from each study were entered into one dataset and data were analyzed using SPSS statistical software, version 28.0 (SPSS Inc., Chicago, USA). Participant characteristics were described using numbers and percentages for describe categorical variables (chi-square analysis), while means and standard deviations were used to describe continuous variables (univariate analysis of variance [ANOVA]). Chi-square, Fisher's exact test, and likelihood ratios were used to compare MSKi history between occupation groups.

Comparisons of physical fitness test results between occupation groups (military v. non-military) were first performed using independent t-tests. Univariate analysis of covariance (ANCOVA) were applied when occupation was significantly related to a physical fitness test result at the t-test. Two-way ANCOVAs were performed to assess the combined relationship between occupation category and parity status with physical fitness outcomes. Covariates included in the ANCOVA were age, parity status, body fat %, and injury history (where applicable). The inclusion of injury history for one-way ANCOVAs were determined by *i)* significant relationship between the injury and the physical fitness test being assessed and *ii)* where more than one injury was eligible, if the injuries were not related to each other, all were included, otherwise the most prevalent injury was selected. Before performing ANCOVAs, the assumption of homogeneity of covariance was tested and confirmed. A three-way analysis of variance (ANOVA) was also used to assess the main effect of i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history + previous RSI history vs. no RSI history; acute injury and RSI history variables were included in the analysis separately), as well as their interaction with the assessed fitness markers. Adjustments for multiple comparisons were performed according to Bonferroni correction (mean difference, 95%

confidence interval [CI]), and the magnitude of potential observed differences was computed as effect sizes (eta squared, η^2). The significance level was set at $p<0.05$.

RESULTS

Fifty-seven female participants employed as first responders and healthcare providers (non-military) were compared to ninety female members of the CAF (military). The participant demographics are outlined in Table 1.

Variable	Non-military (n = 57)	CAF (n = 90)	Significance
Age	36.19 ± 8.2	33.8 ± 7.3	0.070
Height (cm), mean ± SD	166.4 ± 6.6	163.7 ± 18.5	0.282
Bodyweight (Kg), mean ± SD	69.3 ± 11.1	70.3 ± 12.0	0.586
Body mass index (kg/m^2), mean ± SD	24.9 ± 3.9	25.7 ± 4.3	0.223
Body fat %, mean + SD	27.4 ± 8.8	28.9 ± 8.1	0.293
Years of service, mean ± SD	10.3 ± 7.4	10.8 ± 7.1	0.686
Have given birth (%)	52.6	43.3	0.271
Acute injury (%)	77.2	73.3	0.599
Repetitive strain injury (%)	78.9	85.6	0.299

Table 1. Participant demographics for the non-military and military (CAF) groups. Continuous variables were assessed using independent t-tests and are represented as mean and standard deviation (SD). Chi-square test was used for 2x2 comparisons (e.g., parity status and injury history), which are represented in percentages. Significance was set to 0.05.

Physical fitness comparison

The independent t-test comparisons for physical fitness test results are described in Table 2. Some individuals opted to not perform specific physical fitness tests due to current injuries, thus the numbers of participants included for each test are shown in Table 2

Table 2. Physical fitness comparison between females in military and non-military careers

		T-test					ANCOVA				
Fitness Metric	Occupation	N	Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)	Adjusted Mean	Std. Error	Lower bound	Upper bound	Sig.
Sit-and-reach (cm)	Non-military	57	36.7	7.5	0.99	0.266	36.6	1.02	34.58	38.62	0.296
	CAF	88	35.2	8.3	0.88		35.2	0.82	33.59	36.84	
Long jump (cm)	Non-military	57	159.1	25.4	3.37	0.349	159.7	2.85	154.06	165.33	0.395
	CAF	88	163.2	26.7	2.85		162.8	2.29	158.32	167.36	
Medicine ball toss (cm)	Non-military	57	261.3	53.0	7.01	0.086	265.1	7.00	251.25	278.95	0.311
	CAF	88	276.9	52.9	5.64		274.4	5.59	263.33	285.43	
Back squat (lbs.)	Non-military	57	184.4	49.0	6.49	<0.001*	185.4	5.60	174.31	196.47	<0.001 *
	CAF	84	154.3	38.5	4.20		153.6	4.60	144.48	162.68	
Back squat -relative (%)	Non-military	57	122.6	33.3	0.04	<0.001*	121.8	0.03	1.15	1.28	<0.001 *
	CAF	84	101.9	27.6	0.03		102.5	0.03	0.97	1.08	
Bench press (lbs.)	Non-military	57	94.2	25.6	3.40	0.139	94.5	3.10	88.35	100.62	0.099
	CAF	87	88.0	22.7	2.44		87.8	2.50	82.86	92.76	
Bench press -relative (%)	Non-military	57	62.8	18.2	0.02	0.078	62.3	0.02	0.59	0.66	0.023*
	CAF	87	57.7	14.7	0.02		58.0	0.01	0.55	0.61	
Biering Sorenson (seconds)	Non-military	57	166.8	60.2	7.97	0.001*	161.0	6.63	147.85	174.07	0.006*
	CAF	88	133.0	59.4	6.34		136.9	5.29	126.36	147.27	
Single-leg wall right (seconds)	Non-military	56	73.7	43.9	5.86	<0.001*	721.6	4.39	62.92	80.28	<0.001 *
	CAF	88	43.5	26.1	2.78		44.8	3.48	37.96	51.73	
Single-leg wall left (seconds)	Non-military	56	69.5	41.6	5.56	<0.001*	68.4	4.36	59.80	77.04	<0.001 *
	CAF	88	40.5	26.8	2.86		41.2	3.46	34.30	47.99	
Push-up (repetitions)	Non-military	57	24.2	12.1	1.60	0.004*	23.6	1.29	21.01	26.09	0.005*
	CAF	88	18.4	10.7	1.14		18.8	1.03	16.78	20.85	
VO2max (mL/kg/min)	Non-military	53	42.9	7.4	1.02	0.747	42.8	0.78	41.22	44.32	0.555
	CAF	80	43.3	8.4	0.94		43.4	0.64	42.12	44.63	

Table 2. Physical fitness test results compared by occupation groups. Independent t-tests and 1-way ANCOVAs were used. Lower and upper bound refer to 95% confidence interval limits. Covariates included for ANCOVAs were age, body fat %, and parity status with the following exceptions: *i)* Injury history was included when the injury was related to the fitness outcome: Back squat (relative) – wrist and knee injury, Biering-Sorenson – wrist and spine injury, Push-up – wrist injury, Single-leg wall sit right side - lower extremity injury, *ii)* body fat % was removed as a covariate for relative back squat and relative bench press as they were calculated using bodyweight, which was correlated to body fat % using Spearman's *rho* calculation. Significance was set to 0.05.

Musculoskeletal injury comparison

History of acute injury and RSI were reported by 74.8% (p = 0.599) and 83.0% (p = 0.299), respectively. Occupation category was associated with injuries when stratified by body region (see Figure 1 for significant findings only) (see table in Supplementary File 1, chi-square and logistic regression analysis tables comparing musculoskeletal injuries between non-military and military groups).

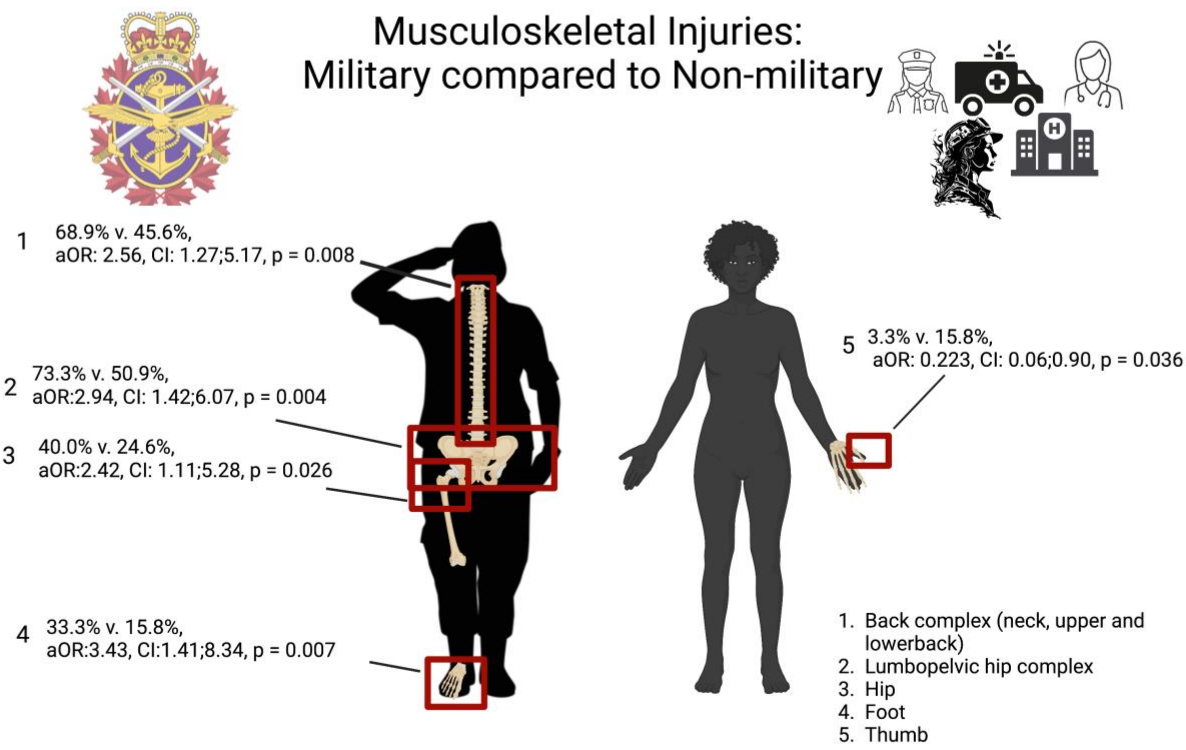

Figure 1. Musculoskeletal injury prevalence and likelihood ratios between military (n = 90) and non-military (n = 57) groups. Prevalence was calculated using chi-square test and logistic regressions were used to establish adjusted odds ratios (aOR). The covariates included were body fat %, parity status, and age. Back complex = low back, upper back, and neck; lumbopelvic hip complex = low back, pelvis, and hip. Significance was set to 0.05.

Physical fitness outcomes when combining occupation, parity status, and musculoskeletal injury history

Significant effects and interactions between occupation (NM vs. CAF), parity status (Parous vs. Nulliparous) and injury history (with or without acute injury history; with or without RSI) were identified. The results from the three-way ANOVA are described below for both acute injury history and RSI history.

Acute injury history

Significant findings are described in Table 3.

Body fat

No significant differences were observed in the main effects or three-way interactions. The results of this analysis are described in Supplementary File 2.

Flexibility

Three-way ANOVA indicated an interaction between occupation and acute injury history only ($F = 5.431$; $p = 0.021$; $\eta^2 = 0.038$). Other non-significant interactions and main effects are described in Supplementary File 2. The multiple correction analysis showed no statistically significant differences, and only a marginally higher flexibility for NM vs. CAF members who have history of acute injuries.

Relative lower body strength

The results of the three-way ANOVA revealed a main effect of occupation ($F = 23.112$; $p = <0.001$; $\eta^2 = 0.148$). According to multiple corrections, NM members presented higher relative lower body strength when compared to CAF members. An interaction between occupation and acute injury history was found ($F = 4.401$; $p = 0.038$; $\eta^2 = 0.032$). Multiple comparison indicated higher strength of the lower limbs for NM vs. CAF in both participants with and without acute injury history. In addition, a three-way interaction was observed ($F = 3.966$; $p = 0.048$; $\eta^2 = 0.029$). Multiple comparisons suggested a difference between NM vs. CAF among parous individuals with no history of acute injury and among nulliparous individuals with a history of acute injury. Among NM members with a history of acute injury, nulliparous participants had higher relative strength than their parous counterparts.

Finally, parous CAF members with acute injury history presented higher strength than parous CAF members without acute injury history.

Lower body power

Three-way ANOVA revealed a main effect of parity status ($F = 4.895$, $p = 0.029$, $\eta^2 = 0.034$) with the nulliparous group jumping further than the parous participants. No other significant findings were observed (described in Supplementary File 2).

Upper body power

No significant main effects or interactions observed. The non-significant findings are described in Supplementary File 2.

Lower body strength

The results of the three-way ANOVA demonstrated main effect of parity status ($F = 5.805$, $p = 0.017$, $\eta^2 = 0.042$) and occupation ($F = 22.982$, $p < 0.001$, $\eta^2 = 0.147$). When adjusted for multiple corrections, the nulliparous group lifted more weight than the parous group through the 4 repetition back squat. The NM group lifted more than the CAF members. An interaction between occupation and acute injury history was also observed ($F = 4.860$, $p = 0.029$, $\eta^2 = 0.035$). NM with a history of acute injury had higher lower body strength than CAF members with acute injury. Main effects and interactions from the three-way ANOVA are further described in Supplementary File 2.

Upper body strength

Three-way ANOVA indicated a main effect for parity status ($F = 4.026$, $p = 0.047$, $\eta^{2\cdot} = 0.029$). The nulliparous group lifted more weight in the 4RM bench press than the parous participants. No other main effects or interactions were observed (described in Supplementary File 2).

Upper body strength relative to bodyweight

No significant interactions or main effects observed, the results from the three-way ANOVA are described in Supplementary File 2.

Lower back muscular endurance

Three-way ANOVA revealed a main effect for occupation ($F = 7.353$, $p = 0.008$, $\eta^{2\cdot} = 0.051$). The NM group achieved longer times in the Biering Sorenson test than the CAF members. No other main effects or interactions were observed (described in Supplementary File 2).

Lower body muscular endurance

Right leg- A main effect for occupation ($F = 18.908$, $p < 0.001$, $\eta^2 = 0.122$) was observed by three-way ANOVA. The NM group held the single-leg wall sit (right) for longer than the CAF members.

Left leg- A main effect for occupation ($F = 18.547$, $p < 0.001$, $\eta^2 = 0.120$) was observed by three-way ANOVA. The NM group held the single-leg wall sit (left) for longer than the CAF members.

No other significant main effects or interactions were revealed (described in Supplementary File 2).

Upper body muscular endurance

Three-way ANOVA revealed a main effect for occupation ($F = 5.682$, $p = 0.019$, $\eta^2 = 0.040$). The NM group performed more push-up repetitions than the CAF members. No other main effects or interactions were observed (described in Supplementary File 2).

Aerobic Capacity

The results of the three-way ANOVA yielded a significant interaction between parity status and a history of acute injury ($F = 4.737$, $p = 0.031$, $\eta^2 = 0.037$). Parous participants with no history of acute injury achieved higher VO_{2max} than parous individuals with acute injury history. No other significant findings for main effects or interactions were observed (described in Supplementary File 2).

Table 3. Significant multiple comparisons derived from three-way ANOVA results: Acute injury history.

Flexibility		
	Mean difference (cm)	**95% CI**
NM vs. CAF (with acute injury history)	3.1	-0.04; 6.27
% lower body strength		
	Mean difference (%)	**95% CI**
NM vs. CAF	0.28	0.17; 0.40
NM vs. CAF (with acute injury history)	0.15	0.04; 0.26
NM vs. CAF (without acute injury history)	0.38	0.13; 0.62
NM vs. CAF (parous without acute injury history)	0.49	0.06; 0.92
NM vs. CAF (nulliparous with acute injury history)	0.31	0.14; 0.48
Parous vs. Nulliparous (NM with acute injury history)	0.24	0.06; 0.41
With vs. without acute injury history (parous CAF members)	0.25	0.04; 0.47
Lower body power		
	Mean difference (cm)	**95% CI**
Parous vs. Nulliparous	-11.55	-21.87; -1.23
Lower body strength		
	Mean difference (lbs.)	**95% CI**
Parous vs. Nulliparous	-20.58	-37.47; -3.69
NM vs. CAF	40.94	24.05; 57.83
NM vs. CAF (with acute injury history)	22.11	6.51; 37.72

Upper body strength		
	Mean difference (lbs.)	**95% CI**
Parous vs. Nulliparous	-9.66	-19.18; -0.14
Lower back muscular endurance		
	Mean difference (sec)	**95% CI**
NM vs. CAF	32.79	8.88; 56.71
Lower body muscular endurance – right leg		
	Mean difference (sec)	**95% CI**
NM vs. CAF	30.39	16.57; 44.22
Lower body muscular endurance – left leg		
	Mean difference (sec)	**95% CI**
NM vs. CAF	29.35	15.87; 42.83
Upper body muscular endurance		
	Mean difference (reps)	**95% CI**
NM vs. CAF	5.44	0.93; 9.95
Aerobic capacity		
	Mean difference (mL/kg/min)	**95% CI**
No acute injury history vs. acute injury history (parous only)	6.39	1.33; 11.45

NM = non-military, CAF = Canadian Armed Forces, reps = repetitions.

Repetitive strain injuries

Significant findings are described in Table 4.

Body fat, flexibility, lower body power, upper body power, upper body strength, aerobic capacity

No significant differences observed in the main effects or interactions for the three-way ANOVA. The results of this analysis are described in Supplementary File 3.

Lower body strength

The results of the three-way ANOVA revealed a main effect of occupation ($F = 5.836$; $p = 0.017$; $\eta^2 = 0.042$). According to multiple corrections, NM members presented higher lower body strength when compared to CAF members. No other main effects or interactions were observed and are described in Supplementary File 3.

Lower body strength relative to bodyweight

The results of the three-way ANOVA demonstrated main effect of occupation ($F = 5.534$, $p = 0.020$, $\eta^2 = 0.040$). When adjusted for multiple corrections, the NM group lifted more weight relative to bodyweight in the 4RM back squat test than the CAF members. No other significant main effects or interactions were observed, and results are further described in Supplementary File 3.

Upper body strength relative to bodyweight

Three-way ANOVA indicated a main effect for occupation ($F = 4.067$, $p = 0.046$, $\eta^{2\cdot} = 0.029$). NM group lifted more weight relative to bodyweight in the 4RM bench press than the CAF members. No other main effects or interactions were observed (described in Supplementary File 3).

Lower back muscular endurance

Three-way ANOVA revealed a main effect for occupation ($F = 5.887$, $p = 0.017$, $\eta^{2\cdot} = 0.041$). The NM group achieved longer times in the Biering Sorenson test than the CAF members. No other main effects or interactions were observed (described in Supplementary File 3).

Lower body muscular endurance

Right leg- A main effect for occupation ($F = 14.273$, $p < 0.001$, $\eta^2 = 0.095$) was observed by three-way ANOVA. The NM group held the single-leg wall sit (right) for longer than the CAF members.

Left leg- A main effect for occupation ($F = 13.804$, $p < 0.001$, $\eta^2 = 0.092$) was observed by three-way ANOVA. The NM group held the single-leg wall sit (left) for longer than the CAF members.

No other significant main effects or interactions were revealed (described in Supplementary File 3).

Upper body muscular endurance

Three-way ANOVA revealed a main effect for occupation ($F = 7.437$, $p = 0.007$, $\eta^2 = 0.051$). The NM group performed more push-up repetitions than the CAF members. No other main effects or interactions were observed (described in Supplementary File 3).

Table 4. Significant multiple comparisons derived from three-way ANOVA results: Repetitive strain injury history.

Lower body strength		
	Mean difference (lbs.)	**95% CI**
NM vs. CAF	24.01	4.35; 43.67
Lower body strength relative to bodyweight		
	Mean difference (%)	**95% CI**
NM vs. CAF	0.16	0.03; 0.30
Upper body strength relative to bodyweight		
	Mean difference (%)	**95% CI**
NM vs. CAF	0.07	0.00; 0.15
Lower back muscular endurance		
	Mean difference (sec)	**95% CI**
NM vs. CAF	33.24	6.15; 60.33
Lower body muscular endurance (right leg)		
	Mean difference (sec)	**95% CI**
NM vs. CAF	29.99	14.29; 45.70
Lower body muscular endurance (left leg)		
	Mean difference (sec)	**95% CI**
NM vs. CAF	28.91	13.48; 44.15
Upper body muscular endurance		
	Mean difference (reps)	**95% CI**
NM vs. CAF	7.01	1.93; 12.10

NM = non-military, CAF = Canadian Armed Forces, reps = repetition

DISCUSSION

To our knowledge, this study is the first direct comparison of physical fitness and MSKi prevalence between active-duty CAF members and non-military individuals employed in arduous occupations. We also contribute the combined impact of parity status and occupation category on physical fitness and MSKi. With no difference in participant demographics (e.g., age, anthropometrics, parity status), the non-military group demonstrated superior strength and muscular endurance, rejecting part of our hypothesis. Injury prevalence was mostly in alignment with what we anticipated in that CAF members were more likely to be injured at multiple body regions, except the thumb.

Physical fitness

Physical employment standards are commonly applied in Canadian first-responder organizations and within the CAF to ensure candidates are physically able to perform the common tasks required in the respective occupation. All members of the CAF must maintain a minimum physical employment standard assessed annually via the Fitness for Operational Requirements of Canadian Armed Forces Employment (FORCE). The FORCE is comprised of 4 components that simulate picking and digging, escape to cover, pickets and wire carry, vehicle extraction, stretcher carry, and sandbag fortification (details found here: https://cfmws.ca/sport-fitness-rec/fitness-testing/cmtfe-force-evaluation/force-evaluation).[11] While the paramedics, law enforcement, and firefighters included in this study must complete a fitness test to be hired, none of the non-military organizations where the participants were employed require annual fitness testing. The first-responder participants indicated having completed at least one of the following pre-hire requirement tests: Ottawa Paramedics Physical Ability Test (OPPAT) (details found here: https://specialprojects.wlu.ca/oppat/), the Candidate Physical Ability Test (CPAT) (details found here:

https://www.fireontario.com/site/occupational-assessment-cpat), and the Physical Readiness Evaluation for Police and PIN (details found here: https://oacpcertificate.ca/physical-preparation/). Comparisons between the physiological demands of these tests, especially the OPPAT, CPAT, and FORCE as they are designed to simulate the most common tasks of the job, could provide valuable insight into differences in physical fitness described in this present study. It is also possible that while members of the CAF train to meet the requirements of the FORCE, the non-military group relies on their own evaluations of what is needed to thrive in their environment. The presence or absence of a benchmark may result in a different perception or definition of physical fitness, with CAF members using the FORCE as an indicator of optimal condition and the non-military group relying on personal experiences, self-motivation, and self-education. The positive relationship between physical fitness performance and exercise self-efficacy has been documented previously and could contribute to better results in the non-military group.[12]

Other factors potentially driving the difference in test scores are exercise behaviours and physical activity. A recent publication by our team examining self-reported MSKi in the CAF indicated that 64.8% of female participants sustained RSI and 51.5% sustained acute injuries from work related physical training.[13] Moreover, our previous work indicates that female CAF members are also more likely to experience physical training limitations due to MSKi and sustain more injuries during the FORCE test compared to male peers.[13,14] These disparities suggest that the current physical training provided might not be sufficient in supporting the female CAF member. This possible deficit in fitness programming is further supported by the greater muscular strength and endurance performance exhibited by the non-military group.

Musculoskeletal injury

The high prevalence of injuries to the back and lower body in the military group is congruent with the literature.[13,15] The majority of the participants included in the CAF study were from 4th Canadian Division Support Base Petawawa (4 CDSG). This base is home to Regular Force and Special Operations Forces with land and air capabilities, all of which have high deployment tempos. Common physical demands placed on members of these units include loaded march and heavy lifting; both are known modifiable risk factors for a plethora of MSKi in military personnel, including those affecting the back and lower extremity.[16-18] Another possible contributor to the injury disparity is the footwear worn by both groups. While combat boots must be worn by CAF members when in uniform, those in the non-military group have more choice when it comes to footwear. Tactical boots impact kinetics and kinematics throughout the body, including restricted functional ankle joint stability and altered muscle activations throughout the lower extremity in standing and through gait (*i.e.*, increase posterior muscle activity). Additionally, when compared to running shoes, combat boots and military shoes yield larger ground reaction force related to impact and force transfer in walking. While footwear is important personal protective equipment for individuals working in military, healthcare, and protective services, the long-term combat boot use may increase injury risk.

The only body region more vulnerable to injury in the non-military group is the thumb and such injuries are likely attributable to the healthcare workers included in the sample. Due to the near constant strain place in the metacarpophalangeal and interphalangeal joints while delivering patient care or treatment, injuries to this body region are especially common among nurses and manual therapy professionals (*i.e.*, physiotherapists, chiropractors, massage therapists).[19] As instability at the thumb joints and weakness of the thumb flexors, extensors and abductors are associated with symptomology at this body region,[19] physical training programs should include exercises aimed at improving thumb strength and stability.

Limitations

This comparison provides valuable insights to future research and policy development for females employed in arduous occupations, but it is not without limitations. The data collection period of the CAF study occurred in Fall 2021, while COVID-19 restrictions were ongoing in the province of Ontario. Access to exercise and physical activity infrastructure throughout that time was limited or inconsistent, possibly impacting the results of the CAF group. While the mean VO_{2max} results from both groups were "excellent" for the average age of the sample, it is possible that the different aims for the studies impacted the motivation for participation. Specifically, the CAF project focused on the impact of MSKi on occupation performance compared to the potential impact of parity status being emphasized for the non-military study. An examination of physical activity and exercise behaviours in both groups could provide important insight into adapting the physical training of female CAF members. It is important to highlight that neither project examined the relationship of pregnancy or the postpartum period with fitness or MSKi. Rather, we examine parity status using a similar method as other studies that view previous injury as a risk for future injury. Longitudinal studies involving female individuals who choose arduous careers are needed to decern the physical impact of childbearing explicitly and the outcomes of access to benefits or support (*i.e.*, maternity leave, return-to-work policies, physical training or rehabilitation programs, access to childcare). Given that resources, job demands, and culture differ greatly between regions and organizations, the agencies and geographical location should also be considered when interpreting the findings in this study.

CONCLUSION

Our findings indicate that in addition to inferior muscular strength and endurance, female members of the CAF experience more injuries involving the back and lower extremity compared to those employed in healthcare or protective services. Further, relative lower body strength is related to parity status when occupation is considered in conjunction with acute injury history. Similar physical fitness support aimed at offsetting the impact of childbirth may benefit female individuals regardless of employment in non-military or military environments. However, occupation was consistently related to physical fitness performance independently and interacted with injury history. The disparities in body regions susceptible to MSKi justify the need for occupation-specific physical training for injury prevention. Thus, initiatives and research supporting females employed in arduous occupations should differentiate between military and non-military populations. Further, injury type and parity status are important considerations when examining physical fitness outcomes in these populations.

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Supplementary Files

Supplementary File 1 - Comparison of musculoskeletal injuries between non-military and military groups.

	Chi-square test				Adjusted odds ratios				
	Total % (n = 147)	Non-military % (n = 57)	CAF % (n = 90)	Sig	Ref	Exp. B	Lower	Upper	Sig
Injury by type									
Acute injury	74.8	77.2	73.3	0.599					
Repetitive strain injury	83.0	78.9	85.6	0.299					
Injury by body region									
Head, neck, shoulder complex *(i)*	53.1	49.1	55.6	0.446					
Head	20.4	15.8	23.3	0.269					
Neck	27.9	19.3	33.3	0.064	Non-military	2.234	0.989	5.043	0.053
Shoulder and upper arm	38.1	38.6	37.8	0.921					
Upper extremity *(ii)*	55.8	47.4	61.1	0.102					
Elbow and lower arm	17.7	19.3	16.7	0.684					
Wrist	23.8	19.3	26.7	0.307					
Hand	9.5	7.0	11.1	0.410					
Thumb	8.2	15.8	3.3	0.011*	Non-military	0.223	0.055	0.903	0.036*

Fingers	8.8	12.3	6.7	0.243					
Lower extremity complex *(iii)*	74.8	68.4	78.9	0.154					
Hip	34.0	24.6	40.0	0.054	Non-military	2.419	1.109	5.275	0.026*
Thigh	8.8	5.3	11.1	0.224					
Knee	43.5	38.6	46.7	0.336					
Lower leg	19.7	12.3	24.4	0.071	Non-military	2.328	0.905	5.987	0.080
Ankle	36.7	35.1	37.8	0.742					
Foot	26.5	15.8	33.3	0.019*	Non-military	3.43	1.412	8.335	0.007*
Toes	6.1	7.0	5.6	0.735					
Spine complex *(iv)*	59.9	45.6	68.9	0.005*	Non-military	2.564	1.273	5.165	0.008*
Upper back	23.1	17.5	26.7	0.201					
Lower back	51.0	40.4	57.8	0.039*	Non-military	1.927	0.966	3.847	0.063
LPHC *(v)*	64.6	50.9	73.3	0.006*	Non-military	2.935	1.42	6.065	0.004*
Abdomen and pelvis	11.6	10.5	12.2	0.754					

Note- Comparison of musculoskeletal injuries between non-military and military groups (CAF). The body complexes were defined as: (*i)* head, neck, shoulder, *ii)* upper extremity (fingers, thumb, hand, wrist, lower arm, elbow upper arm, shoulder), *iii)* lower extremity (hip, thigh, knee, lower leg, ankle, foot, toes), *iv)* spine (low back, upper back, neck), *v)* lumbopelvic hip complex (low back, pelvis, hip). Chi-square analysis was used to compare prevalence, logistic regressions were used to establish adjusted odds ratios. Covariates included were body fat %, parity status, and age. Significance was set to 0.05.

Supplementary file S2 – Interactions and main effects from Three-way ANOVA: Acute injuries

Table S2-1. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on body fat percentage.

Main effects and interactions	F-value	p-value	Eta squared, η^2
Main effects			
Occupation	0.466	0.496	0.003
Parity	0.110	0.741	0.001
Acute injury history	0.195	0.660	0.001
Interactions			
Occupation x Parity	0.496	0.482	0.004
Occupation x Acute injury history	0.329	0.568	0.002
Parity x Acute injury history	3.818	0.053	0.027
Occupation x Parity x Acute injury history	2.719	0.101	0.019

*Significant multiple comparison findings are reported in the main text.

Table S2-2. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on flexibility (Sit-and-Reach test).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.090	0.765	0.001
Parity	0.402	0.527	0.003
Acute injury history	0.062	0.803	<0.001
Interactions			
Occupation x Parity	1.656	0.200	0.012
Occupation x Acute injury history	**5.431**	**0.021***	**0.038**
Parity x Acute injury history	1.430	0.234	0.010
Occupation x Parity x Acute injury history	0.193	0.661	0.001

*Significant multiple comparison findings are reported in the main text.

Table S2-3. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower body strength (4RM back squat) relative to bodyweight.

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	**23.112**	**<0.001***	**0.148**
Parity	3.016	0.085	0.022
Acute injury history	0.016	0.900	<0.001
Interactions			
Occupation x Parity	0.311	0.578	0.002
Occupation x Acute injury history	**4.401**	**0.038***	**0.032**
Parity x Acute injury history	0.080	0.778	0.001
Occupation x Parity x Acute injury history	**3.966**	**0.048***	**0.029**

*Significant multiple comparison findings are reported in the main text.

Table S2-4. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower body power (standing long jump).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.161	0.688	0.001
Parity	4.895	0.029*	0.034
Acute injury history	1.059	0.305	0.008
Interactions			
Occupation x Parity	0.002	0.962	<0.001
Occupation x Acute injury history	0.077	0.782	0.001
Parity x Acute injury history	0.032	0.859	<0.001
Occupation x Parity x Acute injury history	1.819	0.180	0.013

*Significant multiple comparison findings are reported in the main text.

Table S2-5 Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on upper body power (medicine ball toss).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	2.515	0.115	0.018
Parity	0.097	0.756	0.001
Acute injury history	1.682	0.197	0.008
Interactions			
Occupation x Parity	0.399	0.529	0.003
Occupation x Acute injury history	0.014	0.616	<0.001
Parity x Acute injury history	0.037	0.847	<0.001
Occupation x Parity x Acute injury history	0.252	0.906	0.002

*Significant multiple comparison findings are reported in the main text.

Table S2-6. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower body strength (4RM back squat).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	22.982	<0.001*	0.147
Parity	5.805	0.017*	0.042
Acute injury history	0.141	0.708	0.001
Interactions			
Occupation x Parity	0.172	0.679	<0.001
Occupation x Acute injury history	4.860	0.029*	0.035
Parity x Acute injury history	2.761	0.099	0.020
Occupation x Parity x Acute injury history	0.347	0.557	0.003

*Significant multiple comparison findings are reported in the main text.

Table S2-7. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on upper body strength (4RM bench press).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	1.967	0.163	0.014
Parity	4.026	0.047*	0.029
Acute injury history	0.669	0.415	0.005
Interactions			
Occupation x Parity	0.027	0.870	<0.001
Occupation x Acute injury history	0.028	0.868	<0.001
Parity x Acute injury history	0.023	0.870	<0.001
Occupation x Parity x Acute injury history	0.364	0.547	0.003

*Significant multiple comparison findings are reported in the main text.

Table S2-8. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on upper body strength (4RM bench press) relative to bodyweight.

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	3.116	0.080	0.022
Parity	2.375	0.126	0.017
Acute injury history	0.130	0.719	0.001
Interactions			
Occupation x Parity	0.012	0.912	<0.001
Occupation x Acute injury history	0.051	0.822	<0.001
Parity x Acute injury history	1.221	0.271	0.009
Occupation x Parity x Acute injury history	3.742	0.055	0.027

*Significant multiple comparison findings are reported in the main text.

Table S2-9. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower back muscular endurance (Biering-Sorenson test).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	7.353	0.008*	0.051
Parity	1.596	0.209	0.012
Acute injury history	2.044	0.155	0.015
Interactions			
Occupation x Parity	0.106	0.745	0.001
Occupation x Acute injury history	0.021	0.885	<0.001
Parity x Acute injury history	0.311	0.578	0.002
Occupation x Parity x Acute injury history	0.494	0.483	0.004

*Significant multiple comparison findings are reported in the main text.

Table S2-10. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower body muscular endurance (right left wall sit).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	18.547	<0.001*	0.120
Parity	0.614	0.435	0.004
Acute injury history	1.347	0.248	0.010
Interactions			
Occupation x Parity	0.205	0.652	0.002
Occupation x Acute injury history	0.043	0.835	<0.001
Parity x Acute injury history	0.182	0.670	0.001
Occupation x Parity x Acute injury history	0.526	0.470	0.004

*Significant multiple comparison findings are reported in the main text.

Table S2-11. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower body muscular endurance (left leg wall sit).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	3.116	0.080	0.022
Parity	2.375	0.126	0.017
Acute injury history	0.130	0.719	0.001
Interactions			
Occupation x Parity	0.012	0.912	<0.001
Occupation x Acute injury history	0.051	0.822	<0.001
Parity x Acute injury history	1.221	0.271	0.009
Occupation x Parity x Acute injury history	3.742	0.055	0.027

*Significant multiple comparison findings are reported in the main text.

Table S2-12. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on upper body muscular endurance (maximum push-up repetitions).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	5.682	0.019*	0.040
Parity	0.196	0.659	0.001
Acute injury history	0.105	0.740	0.001
Interactions			
Occupation x Parity	0.126	0.724	0.001
Occupation x Acute injury history	0.273	0.602	0.002
Parity x Acute injury history	1.277	0.261	0.009
Occupation x Parity x Acute injury history	1.028	0.312	0.007

*Significant multiple comparison findings are reported in the main text.

Table S2-13. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on aerobic capacity (VO_{2max}).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.019	0.891	0.000
Parity	0.348	0.556	0.003
Acute injury history	2.883	0.092	0.023
Interactions			
Occupation x Parity	1.084	0.300	0.009
Occupation x Acute injury history	0.048	0.827	0.000
Parity x Acute injury history	4.737	0.031*	0.037
Occupation x Parity x Acute injury history	0.333	0.565	0.003

*Significant multiple comparison findings are reported in the main text.

Supplementary file S3 – Interactions and main effects from Three-way ANOVA: Repetitive strain injuries

Table S3-1. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on body fat percentage.

Main effects and interactions	F-value	p-value	Eta squared, η^2
Main effects			
Occupation	0.377	0.540	0.003
Parity	1.334	0.250	0.010
Repetitive strain injury history	0.857	0.356	0.006
Interactions			
Occupation x Parity	0.449	0.504	0.003
Occupation x Repetitive strain injury history	0.018	0.894	<0.001
Parity x Repetitive strain injury history	0.560	0.456	0.004
Occupation x Parity x Repetitive strain injury history	0.920	0.339	0.007

*Significant multiple comparison findings are reported in the main text.

Table S3-2. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on flexibility (sit-and-reach test).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.197	0.658	0.001
Parity	0.001	0.975	<0.001
Repetitive strain injury history	0.232	0.631	0.002
Interactions			
Occupation x Parity	0.092	0.762	0.001
Occupation x Repetitive strain injury history	**0.424**	**0.516**	**0.003**
Parity x Repetitive strain injury history	0.057	0.812	<0.001
Occupation x Parity x Repetitive strain injury history	2.195	0.141	0.016

*Significant multiple comparison findings are reported in the main text.

Table S3-3. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on lower body power (standing long jump).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.678	0.412	0.005
Parity	2.350	0.128	0.017
Repetitive strain injury history	0.350	0.555	0.003
Interactions			
Occupation x Parity	0.361	0.549	0.003
Occupation x Repetitive strain injury history	0.200	0.655	0.001
Parity x Repetitive strain injury history	0.580	0.448	0.004
Occupation x Parity x Repetitive strain injury history	0.037	0.848	<0.001

*Significant multiple comparison findings are reported in the main text.

Table S3-4. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on upper body power (medicine ball toss).

Main effects and interactions	F-value	p-value	Eta squared, η^2
Main effects			
Occupation	2.258	0.135	0.016
Parity	1.889	0.172	0.014
Repetitive strain injury history	0.235	0.629	0.002
Interactions			
Occupation x Parity	0.923	0.339	0.007
Occupation x Repetitive strain injury history	0.026	0.871	<0.001
Parity x Repetitive strain injury history	3.283	0.072	0.023
Occupation x Parity x Repetitive strain injury history	1.144	0.287	0.008

*Significant multiple comparison findings are reported in the main text.

Table S3-5. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on lower body strength (4RM back squat).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	**5.836**	**0.017***	**0.042**
Parity	0.486	0.487	0.004
Repetitive strain injury history	0.096	0.757	0.001
Interaction			
Occupation x Parity	0.810	0.370	0.006
Occupation x Repetitive strain injury history	**1.364**	**0.245**	**0.010**
Parity x Repetitive strain injury history	1.121	0.292	0.008
Occupation x Parity x Repetitive strain injury history	**0.033**	**0.875**	**<0.001**

*Significant multiple comparison findings are reported in the main text.

Table S3-6. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on upper body strength (4RM bench press) relative to bodyweight.

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	5.534	0.020*	0.040
Parity	0.833	0.363	0.006
Repetitive strain injury history	2.422	0.122	0.018
Interactions			
Occupation x Parity	1.717	0.192	0.013
Occupation x Repetitive strain injury history	1.177	0.280	0.009
Parity x Repetitive strain injury history	0.821	0.366	0.006
Occupation x Parity x Repetitive strain injury history	0.038	0.846	<0.001

*Significant multiple comparison findings are reported in the main text.

Table S3-7. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on upper body strength (4RM bench press).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	3.659	0.058	0.026
Parity	1.509	0.221	0.011
Repetitive strain injury history	2.811	0.096	0.020
Interactions			
Occupation x Parity	0.304	0.582	0.002
Occupation x Repetitive strain injury history	0.412	0.522	0.003
Parity x Repetitive strain injury history	0.855	0.357	0.006
Occupation x Parity x Repetitive strain injury history	0.143	0.706	0.001

*Significant multiple comparison findings are reported in the main text.

Table S3-8. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on upper body strength (4RM bench press) relative to bodyweight.

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	4.067	0.046*	0.029
Parity	1.522	0.220	0.011
Repetitive strain injury history	0.309	0.579	0.002
Interactions			
Occupation x Parity	1.110	0.294	0.008
Occupation x Repetitive strain injury history	0.314	0.576	0.002
Parity x Repetitive strain injury history	0.989	0.322	0.007
Occupation x Parity x Repetitive strain injury history	0.001	0.972	<0.001

*Significant multiple comparison findings are reported in the main text.

Table S3-9. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on lower back muscular endurance (Biering-Sorenson test).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	5.887	0.008*	0.051
Parity	1.258	0.209	0.012
Repetitive strain injury history	0.000	0.998	0.000
Interactions			
Occupation x Parity	0.203	0.653	0.001
Occupation x Repetitive strain injury history	0.000	0.994	0.000
Parity x Repetitive strain injury history	0.392	0.532	0.003
Occupation x Parity x Repetitive strain injury history	0.070	0.792	0.001

*Significant multiple comparison findings are reported in the main text.

Table S3-10. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous acute injury history vs. no acute injury history) and their effect and interactions on lower back muscular endurance (right leg wall sit).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	14.273	<0.001*	0.095
Parity	0.090	0.765	0.001
Repetitive strain injury history	0.130	0.719	0.001
Interactions			
Occupation x Parity	0.839	0.361	0.006
Occupation x Repetitive strain injury history	0.004	0.951	0.000
Parity x Repetitive strain injury history	0.046	0.830	0.000
Occupation x Parity x Repetitive strain injury history	1.956	0.164	0.014

*Significant multiple comparison findings are reported in the main text.

Table S3-11. Findings from three-way ANOVA involving the factors i) occupation (CAF vs. NM members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on lower body muscular endurance (left leg wall sit).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	13.804	<0.001	0.092
Parity	0.252	0.616	0.002
Repetitive strain injury history	0.835	0.362	0.006
Interactions			
Occupation x Parity	0.015	0.904	0.000
Occupation x Repetitive strain injury history	0.008	0.913	0.000
Parity x Repetitive strain injury history	0.003	0.955	0.000
Occupation x Parity x Repetitive strain injury history	0.657	0.419	0.005

*Significant multiple comparison findings are reported in the main text.

Table S3-12. Findings from three-way ANOVA involving the factors i) occupation (NM vs, CAF members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on upper body muscular endurance (maximum push-up repetitions).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	7.437	0.007*	0.051
Parity	0.234	0.629	0.002
Repetitive strain injury history	0.161	0.689	0.001
Interactions			
Occupation x Parity	0.777	0.379	0.006
Occupation x Repetitive strain injury history	0.294	0.589	0.002
Parity x Repetitive strain injury history	0.389	0.534	0.003
Occupation x Parity x Repetitive strain injury history	0.006	0.936	0.000

*Significant multiple comparison findings are reported in the main text.

Table S3-13. Findings from three-way ANOVA involving the factors i) occupation (NM vs, CAF members); ii) parity (parous vs. nulliparous); and iii) injury history (previous repetitive strain injury history vs. no repetitive strain injury history) and their effect and interactions on aerobic capacity (VO_{2max}).

Main effects and interactions	**F-value**	**p-value**	**Eta squared, η^2**
Main effects			
Occupation	0.153	0.696	0.001
Parity	0.380	0.539	0.003
Repetitive strain injury history	0.182	0.670	0.001
Interactions			
Occupation x Parity	0.465	0.497	0.004
Occupation x Repetitive strain injury history	0.041	0.839	0.000
Parity x Repetitive strain injury history	0.001	0.970	0.000
Occupation x Parity x Repetitive strain injury history	0.412	0.522	0.003

*Significant multiple comparison findings are reported in the main text.

Chapter 7

Discussion and Conclusion

Collectively, this work aimed to investigate the relationship between parity status and MSKi in female CAF members. Ultimately, a history of childbirth was related to MSKi prevalence in female members of the CAF, but physical fitness performance of active-duty members who been injured and given birth performed better in muscular endurance and strength compared to their nulliparous peers. When performing the same comparison for females employed in non-military arduous careers (an occupation that has clearly described physical fitness requirements within the hiring criteria and may include a minimum physical employment standard test [*i.e.,* firefighting, law enforcement, paramedicine, healthcare]), the parous group did not perform as well as the nulliparous participants. As such, there are 4 specific outcomes a reader should take away from this thesis, and they are:

i) CAF members with a history of childbirth sustain more RSI, overall and at both the foot and wrist, compared to their nulliparous peers.

ii) CAF members, in our sample, who continued to serve after both MSKi and pregnancy performed better in the lower back muscular endurance and flexibility compared to nulliparous members of the same occupation category (Purple Trades). These physical fitness attributes may be important in overcoming physical trauma and continuing military service.

iii) Movement compensations after childbirth should be considered in conjunction with injury history. Applying the bodyweight OHS to assess MKD could be used to help practitioners identify knee valgus (unilateral and asymmetrical) in female members returning from MSKi and postpartum.

iv) The physical health and fitness of female CAF members who have sustain MSKi are not consistent with females employed in non-military arduous occupations. Thus, health initiatives and research unique to the CAF are recommended.

While this thesis contributes a connection between parity status and MSKi, it is unclear when these injuries occurred. It is possible the tissue trauma was sustained because of changes during pregnancy and the postpartum period, or if the injuries can be attributed to changes that remained after childbearing. Many aspects of daily life change when becoming a parent, some of which could also contribute to the parous members being at greater risk. Examining if similar injuries occur in females who adopt infants or males who are the primary caregiver could indicate if childbearing or childrearing is primarily responsible for these injuries. Physical activity and exercise participation, for example, often changes after bearing children. This has a considerable impact on the body and how a person can interact with their environment. These behaviour changes, specifically decreases in physical activity, are seen throughout pregnancy and often continue beyond the postpartum period.[1,2]

After injury and maternity leave are two common timepoints of attrition for female CAF members. The studies included in this thesis provide valuable information for leadership and practitioners supporting female military members returning from both MSKi and maternity leave. It appears that to overcome both MSKi and childbirth, high levels of physical fitness are achievable. Specifically, lower back muscular endurance and flexibility are of particular importance in personnel who have given birth. Further, screening for asymmetries in lower body muscular endurance and knee valgus in individuals with previous injury or after pregnancy should be performed to inform physical training programs. Given that the parous group performed better than nulliparous peers in the CAF sample, but the opposite was true for the non-military sample, it can be theorized that those who do not obtain the necessary strength and endurance adaptations release from military service. Implementing a physical fitness evaluation as a component of the 'release from service' process could provide valuable insight for specific physical fitness components to incorporate into interventions. The altered knee kinematics observed in the bodyweight OHS in members who had been injured and given birth compared to the nulliparous non-injured group highlights the possibility that movement competency may be involved in the elevated MSKi prevalence in CAF members. Thus, it may also be valuable to include a movement screen, like the OHS, in the physical proposed fitness assessment at 'release from service'. This would indicate if compensatory movement patterns were playing a role in the medical (physical or psychological) release of CAF members.

The utilization of movement screens is becoming more common in workplace and sport related fitness evaluations. Evidence supporting this type of assessment in relation to MSKi is mixed and the effectiveness of specific movement screens seems to be dependent on the population. A recent systematic review and meta-analysis by Moore *et al* [3] assessed MSKi prediction by the Functional Movement Screen (FMS). Moore *et al* indicated an FMS score threshold of $\leq$14 was predictive for rugby and baseball, associations trended toward significant for American football and ice hockey, but no relationship observed for soccer, running, or mixed sport sub-groups.[3] Additionally, the authors found a relationship between a total score $\leq$14 and injury severity for males but not females, and called for more sex-specific research to be done in this area as data is limited.[3] The relationship between parity status combined with injury history and medial knee displacement described in this thesis suggests females may also need to be further categorized into parous and nulliparous. To note, more robust assessments of the relationship between parity status and joint kinematics should be performed to confirm these findings. Additionally, chronological considerations (*i.e.*, injury before or after pregnancy, when injury and delivery occurred) need to be researched to guide optimal intervention or assessment timeframes. Applying the OHS to assess kinematic differences in relation to parity status and injury history at different joints and on different planes of motion may also be valuable. These recommendations are supported by the altered joint loading and motion at the ankle and knee between trimesters and postpartum outlined by Bagwell *et al.*, 2020.[4] To note, when comparing parous individuals without accounting for injury history, there appears to be no difference in knee kinematics on the frontal plane compared to nulliparous peers. While much work is needed to understand the relationship between greater knee valgus in parous females with a history of acute injury specifically, the preliminary evidence outlined in this thesis supports the inclusion of the OHS as a potentially helpful tool for designing physical training programs for CAF members.

As military leadership around the world work to have female-inclusive or female-specific policy, future studies examining the relationship between childbearing and MSKi timelines in military personnel are needed. An important aspect to improve upon from the studies included in this thesis would be to include injury diagnosis dates in cross-sectional studies or to perform longitudinal investigations that capture injuries at various stages of the female reproduction timeline (e.g., pre-conception, pregnancy, the postpartum period, and after return-to-duty).

Support in the form of physical or mental health, childcare, modified duties during return-to-work, and access to resources could also determine the outcomes of an injury or after childbirth. Support services in the military context have traditionally been tailored to men and males, leaving large gaps for the female membership.[5]

Female CAF members have identified the perceived challenges associated with accessing supports available after pregnancy and the postpartum increase MSKi risk perception.[5] Thus, a final goal of this thesis was to determine if the relationships observed between parity status, MSKi, and physical fitness in the CAF sample were transferable to personnel in similar roles from a non-miliary environment. The opposing findings displayed by the non-military group (parous individuals demonstrating lower fitness performance) highlights the unique needs of female service members. Presently, combining studies performed on first responders and military is fairly common in systematic reviews.[6,7] Trials are also conducted on non-military personnel to inform policy or practices.[8] Based on the conflicting findings in the CAF Purple Trade members compared to civilian equivalents, merging these populations in future reviews is not recommended.

More female individuals are choosing lifelong careers in arduous occupations and female athletes are returning to sport after having children.[9,10] The association between parity status and physical fitness must continue to be examined. As the non-military group performed better than the CAF sample in our protocol, and the relationships between parity status with physical fitness were opposite in these respective groups (e.g., better in parous individuals in the CAF and better in the nulliparous individuals in the non-military), occupation-specific investigations are needed.

The medical and health support female CAF members receive compared to civilians may contribute to the disparities outlined in this thesis. Presently, the medical training of CAF Health Services members is thought to be insufficient to support female members.[11,12] Further, approximately 85% of the CAF population is male.[13] The medical practitioners therefore may not have consistent education or experience in supporting the female membership. The negligible amount of research available for evidence-based protocols or informed choices, furthers the ambiguity around safe practices for non-male personnel who choose careers in the CAF. Ultimately, after reviewing the current policies, it seems many of those pertaining to women's health and female reproduction are non-specific and leave many decisions to the discretion of the member, Commanding Officer, or Medical Officer.

This is first examination of the relationship between parity status and MSKi in CAF members and females employed in arduous occupations in Canada. While the contributions to clinical practice and the academy are evident, there are limitations to this thesis. The lack of physical activity and exercise information in the CAF studies restricts intervention recommendations. It is unknown if the participants of the fitness testing protocol were provided post-partum physical training for example. Though, it can be inferred from the questionnaire data in Chapter 2 that it is unlikely the members did receive specialized support through pregnancy or the postpartum period. Another limitation that was mentioned previously, is the lack of time related information for injuries or pregnancy and the lack of details surrounding the healing process (i.e., time off work, tissue trauma severity, social support through rehabilitation). Insight into the life demands of the CAF member and access to resources would have provided valuable context for the results. Finally, none of the studies included in this thesis were intended to indicate causality.

Instead, they provide important considerations for future question development in both research and clinical practice. As there is biological plausibility for the associations identified between parity status and MSKI, following Hill's Criteria for Causality future studies should assess these interactions further to identify consistency, reproducibility starting with the moderate and strong associations identified in this thesis (e.g., RSI more likely in parous CAF members) as they have a higher probability of being causal.[14]

Childbirth is a substantial musculoskeletal event that is related MSKi. Females who have sustained an injury prior to childbirth may develop undesirable knee movement and have altered physical fitness adaptations. Conversely, it is possible that injury after pregnancy is driving these changes, with childbirth contributing to MSKi in the same way previous injury is a predictor for future injury. Regardless of which event occurs first, females who have MSKi and childbirth history require a specialized approach to physical training compared to nulliparous peers. Additionally, policies and initiatives aimed at supporting females who choose careers in arduous roles should be informed by occupation-specific evidence. The studies outlined in this thesis provide justification for more expensive and resource-heavy study designs to examine parity status as a risk factor for MSKi in military populations.

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Appendices

Appendix 1. Completed works and awards during doctoral program.
Awards

Graduate Admissions Scholarship, University of Ottawa
2020 – 2024
Queen Elizabeth II Graduate Scholarship in Science and Technology (QEII-GSST) 2021 – 2022
Major Sir Frederick Banting MC, RCAMC Medal, Canadian Armed Forces 2022
Queen Elizabeth II Graduate Scholarship in Science and Technology (QEII-GSST) 2022 – 2023
Queen Elizabeth II Graduate Scholarship in Science and Technology (QEII-GSST) 2023 – 2024

Abstracts and Conferences

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Puranda, J.L., da Silva, D.F., Edwards, C.M., Nagpal, T.S., Souza, S.C.S., Semeniuk, K., Adamo, K.B. Characterizing the associations between reproductive health and musculoskeletal injuries of female members of the Canadian Armed Forces. Interdisciplinary Student Research Conference on Healthcare. 2021.

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Puranda, J.L., da Silva, D.F., Edwards, C.M., Nagpal, T.S., Souza, S.C.S., Semeniuk, K., Adamo, K.B. Sleep characteristics associated with musculoskeletal injuries in female Canadian Armed Forces members. International Congress on Soldiers' Physical Performance, London, UK. 2023.

Puranda, J.L., da Silva, D.F., Deroche, F., Edwards, C.M., Nagpal, T.S., Souza, S.C.S., Semeniuk, K., Mclean, L., Adamo, K.B. Characteristics associated with pelvic floor disorders among female Canadian Armed Forces members. International Congress on Soldiers' Physical Performance, London, UK. 2023.

Miller, É., Puranda, J.L., Edwards, C. M., Semeniuk, K., Adamo, K.B. Associations between body composition and physical performance in female Canadian Armed Forces members. Canadian Institute for Military and Veterans Research, CIMVHR Forum 2023. Gatineau, Canada. 2023.

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Publications

Edwards, C. M., da Silva, D.F., Puranda, J.L., Souza, S.C.S., Nagpal, T.S., Semeniuk, K., Adamo, K.B. (2022). Body regions susceptible to musculoskeletal injuries in Canadian Armed Forces pilots. *Journal of Military and Veterans' Health*, *30*(3). https://doi.org/https://doi-ds.org/doilink/09.2022-77624423/JMVH

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Edwards, C. M., da Silva, D.F., Miller, É., Puranda, J.L., Semeniuk, K., Adamo, K.B. Are physical fitness, a history of childbirth, and injury history related to knee valgus in female Canadian Armed Forces members during a bodyweight overhead squat movement? *BMJ Military Health*. (Pre-print)