

# **Characterizing Reproductive Health and Performance Outcomes in Female Canadian Armed Forces Members with a History of Lower Body Injuries**

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## **Abbreviations**

MSKi – Musculoskeletal injuries

RSI – Repetitive strain injuries

CAF – Canadian Armed Forces

HC – Hormonal contraceptives/Hormonal birth control

US – United States

UK – United Kingdom

RED-S – Relative energy deficiency in sport

ACL – Anterior cruciate ligament

EMS – Emergency medical support

BMI – Body mass index

aOR – Adjusted odds ratio

CI – Confidence interval

Sig. - Significance

FORCE – Fitness for Operational Requirements of Canadian Armed Forces Employment

VO<sub>2</sub>max – Maximal oxygen uptake

RM – Repetition maximum

ANOVA – Analysis of Variance

ANCOVA – Analysis of Covariance

## Abstract

Female representation in the Canadian Armed Forces (CAF) is at the highest it has been (16.48%) since women were allowed to integrate in 1965. While the sex ratio is similar to our allies, the government of Canada aims to increase the female membership to 25% by 2026 and have prioritised identifying avenues to increase recruitment and retention. Musculoskeletal injuries (MSKi), specifically repetitive strain injuries (RSI), are a leading cause of attrition in female service members of the CAF. Understanding what health and performance factors are associated with the increased attrition related to RSIs may help further the knowledge that can support female service members throughout each phase of their career. This thesis undertook two studies that aimed to uncover how reproductive health and lower body performance was associated with lower body RSI. The goal of the first study was to ascertain if female reproductive health characteristics (i.e., irregular menstruation, hormonal birth control use, late age of menarche, parity) were associated with lower body RSI (e.g., knee, ankle, foot, etc.), and if so, which ones. Cross-sectional data were collected via questionnaire from n=2,001 (female n=855) service members of the CAF. Females who had reported experiencing irregular menstruation were more likely to report having sustained a hip, knee, or lower leg RSI, while those having given birth reported RSIs of the foot more often. The objective of the second study was to see whether previous RSI in the lower body was associated with poorer lower body physical performance compared to those who had not sustained a previous lower body RSI. A set of 90 female service members underwent a series of tasks such as, sit-and-reach, long jump, back squat, wall-sit, and treadmill VO<sub>2</sub>max. Female service members who reported a previous ankle RSI were found to be associated with higher VO<sub>2</sub>max compared to those not reporting ankle RSI. Together, the results of the thesis demonstrate and identify potential reproductive health and physical performance factors associated with lower body RSI in female service member.

## Chapter 1 Introduction

The Canadian Armed Forces (CAF) is a military that prioritises operational readiness when it comes to peace keeping and disaster response, within Canada and around the world. Opportunities for employment were extended nearly fully for female service members in the CAF in 1971 (1). As of 2023, 16.48% of the CAF are female, while the highest in Canadian history, falling short of the target goal of 25% (2). While there are many possible reasons for the smaller female representation, an area of particular interest is medical discharge (3). One of the leading reasons for medical release in female service members is musculoskeletal injuries (MSKi) (4). MSKi consist of injuries to the musculoskeletal system that include trauma to the tendons, ligaments, muscles, bones, and/or nerves (5). Repetitive strain injuries (RSI), the overuse or repetition of a movement causing pain or injury, are a type of MSKi and are the most prevalent injury type sustained by female service members in the CAF (6,7). Hip, foot, and knee RSI are prominent injuries reported by female CAF members (24.4 to 38.5%, depending on military environment) (7). With the goal of increasing female representation in the CAF, factors associated with RSI must be investigated.

Militaries around the globe have identified notable risk factors for RSI, including aspects of female reproductive health (8). For example, irregular menstruation, and pregnancy are associated with overall RSI in female CAF members (9,10). Whereas, in athletic populations hormonal birth control (HC) has been noted as a potential prevention tool for MSKi (11). Physical performance has also been correlated with RSI in female service members (8,12,13). With the growing number of females in the CAF, understanding how both reproductive health and physical performance relate to RSI reporting is essential to operational readiness.

This thesis includes two studies of female service member in the CAF. The first study examines the associations between reproductive health characteristics and lower body RSI. The second study sought to find links between previous RSI of the lower body with lower body physical performance. These studies aim to illustrate whether reproductive health and physical performance are points of interest for female service members in the CAF, and whether future longitudinal studies are needed to further showcase the impact of lower body RSI on service longevity.

## *1.1 Objectives and Hypotheses:*

*Objective 1:* To investigate the association between aspects of reproductive health in Canadian female service members (e.g., menstrual cycle, parity, hormonal contraceptive use, age of menarche) and the history of lower body repetitive strain injury.

*Hypothesis:* We hypothesize that the characteristics listed below, independently or in combination, will be associated with a higher likelihood of a history of lower body RSI.

- i) Experiencing irregular menstruation.
- ii) Absence of hormonal birth control use.
- iii) Having been pregnant while serving.
- iv) Having experienced a later onset of menarche.

*Objective 2:* To compare physical performance scores of 5 physical tasks (e.g., Back squat, sit-and-reach, long jump, single leg wall sits, VO<sub>2</sub>max) with the rate of lower body RSI in female service members in the CAF.

*Hypothesis:* Female service members having reported previous lower body RSI will have lower physical performance results than those reporting no history of lower body RSI.

## *1.2 Study Rationale*

In 2016 the CAF publicized their goal of increasing female representation to 25% by 2026. To meet this goal, improvement in retention and recruitment of female CAF members is key, yet research related to this population is minimal. Investigations around female-centric factors contributing to MSKi risk need to be prioritized. Globally, research conducted on service members from the US, UK, and Israel, indicate reproductive health and physical performance are related to RSI (14). To the best of our knowledge, lower body RSI prevalence in active-duty female CAF members have yet to be explored. We aim to help identify risk factors and characteristics of internal (i.e., reproductive health) and external (i.e., performance) characteristics where female CAF members are at a higher likelihood of being associated with RSI. This exploration will guide strategies to better mitigate RSI in serving members of the CAF, ultimately helping to increase the retention and recruitment of females.

## Chapter 2 Review of the Literature

### *2.1 Reproductive Health vs Musculoskeletal Injuries*

The age of military service members in Canada ranges from 18 to 60, capturing the reproductive window for both males and females. While sex is a risk factor for MSKi among military populations, it is but one potential contributor to consider (5). In 2020, our team performed a scoping review identifying aspects of female reproductive health as a potential association with MSKi among female CAF members (5). Though not all RSI are associated with reproductive health, many studies have pointed to the importance of distinguishing the female specific hormonal influence on injury rates (9,10,15). Unfortunately, there is a paucity of published literature exploring this relationship in the female CAF population.

Female reproductive health covers a broad spectrum of characteristics. While these characteristics can include irregular menstruation, pregnancy, postpartum and more, several play a role in MSKi rates. Examining service members from the US and the UK demonstrates that female reproductive health contributes to the performance and overall well-being of the member (14,16). Specifically, data from the US Army found that stress fractures occurred at a higher rate in female service members, with multiple risk factors relating to female reproductive health (e.g., menstrual irregularities, hormonal imbalance) during their service time. (14) Additionally, compared to pre-pregnancy, the British Army noted that well-being after pregnancy was quite low, and further, this sub-optimal health increased the risk of MSKi postpartum within service members (16). In the CAF population, our team reported that overall acute injuries and RSI were associated with reproductive characteristics, such as endometriosis, menstrual irregularity, and parity status (9). Not identifying the specific body regions impacted by these injuries, has hindered preventative action development.

Secondary amenorrhea, or irregular menstrual cycle periodicity, occurs in females that engage in vigorous activity, and/or repetitive weight-bearing tasks, while experiencing energy deficiency (17). In athletic female civilian populations, MSKi are associated with health disorders such as relative energy deficiency in sport (RED-S) (18). RED-S can involve low energy, absence of menstruation (in females), disordered eating, and low bone mineral density (18). Both male and female athletes experience RED-S; however, bone health becomes increasingly impacted when females experience amenorrhea with RED-S(18). Female service members diagnosed with RED-S, are at high risk for stress fractures, thought to be due to the lack of menstruation, low bone mineral density, and low energy intake (19,20). In UK elite athletes, RED-S was used as a measure of injury rates in a retrospective study. Of the athletes in the study, 37.7% of the female participants had menstrual dysfunction (20). It was identified that 22.5% of the injury locations were in the ankle and foot, with the majority being muscular injuries (21). While many studies show the links between amenorrhea, RED-S and increased MSKi (20), more research is needed to understand the full magnitude of these risk factors in the female CAF population and the lower body.

In civilian populations, estrogen deficiencies (14), associated with irregular menses, are known to cause decreased bone remodeling and turnover in the cortical layer, leading to higher rates of MSKi (22). Irregular menstrual cycle periodicity has been shown to increase the risk of MSKi in female recruits in the US military (23,24). Within the female CAF population who had a history of overall acute and RSI injuries during service, a significant portion of females had experienced a lack of menses at some point during service (9). Furthermore, lack of menstruation was found to increase the rate of lower extremity fracture risk by threefold among US female recruits, particularly in the pelvis and femur (23,25). Research focused on irregular menstruation

in active female service members and their lower body RSI risk throughout CAF service is limited.

In addition to amenorrhea brought on by high physical activity and low energy intake, hormonal contraceptives (HC) can cause temporary irregular menstrual cycles (14). HC use amongst female service members is significantly higher than in the general population (29.4%), with 34.4% of US service members using them and 31% in the UK (26,27). In fact, 86% of female service members in the US expressed the desire to use HC to control their menstrual cycles (27). Female US military members wished to artificially halt their menses to be more comfortable with occupational field training and deployment (27). As such, various types of HC are being used in the military, and their effects on reproductive health differ depending on the chemical content and reason for using. It is important, therefore, to examine the desired outcome of the individual and chemical make-up of the HC prior to commencing usage. This is further supported by evidence conducted on female recruits in the UK using HC (combined estrogen and progesterone pills), who experienced decreased bone formation and resorption (26). In contrast, those using HC containing depot-medroxyprogesterone acetate had decreased cortical bone integrity of the tibia (26). It was also shown that HC use in female recruits was associated with lower bone mineral density in the spine, and hip (14,22). This increased risk of bone stress injury in military populations highlights the importance of future examination of appropriate HC compounds for servicewomen at all stages of their career.

Though bones are altered by HC use, soft tissue such as ligaments and tendons are also impacted. Amidst the HC literature, relaxin, estrogen, and progesterone, the key drivers of menstrual cycles, were each noted to influence injury risk independently (28). By controlling the natural fluctuation, relaxin becomes increasingly decreased, which provides a protective

mechanism in the ligaments by lowering laxity (11). Whereas the stabilization of estrogen and progesterone from HC influences tissue strength of ligaments and decreases stiffness in tendons thus providing a level of protection from injuries, specifically, ligament ruptures, and muscle strains (28,29). As well, with estrogen being at a controlled level while using HC, muscle synthesis after intense exercise was found to be significantly lower compared to non-HC users (30–32) (33). There is currently no consensus in the literature on the use of HC for MSKi prevention in soft tissue, in particular, MSKi to the anterior cruciate ligament (ACL). The ACL is a highly relevant soft tissue as it is one of the most vulnerable ligaments in female athletes (34), and military populations (35). Women in civilian populations who were not HC users were found to be at a 20% higher relative risk than those who were reported as long-term HC users (36). When taking age into account, re-injury rates of the ACL were only seen to be significantly less in HC users between the ages of 15-19, by 18% (37). Ultimately, there is a gap in knowledge surrounding the long-term effects of HC on injury prevention and rehabilitation, especially in military populations.

The process of childbearing is a monumental female reproductive event. The pregnancy and postpartum period represent a phase of MSKi vulnerability rarely examined in military populations. Pregnancy is a multifaceted life stage that changes the female body in a variety of ways, including weight gain coupled with change in centre of mass, increases in cardiac output and stroke volume (38), as well as surges of relaxin (39). Presumably, these pregnancy-related changes contribute to increased RSI rates within the upper body (40) and lower extremities, mainly stress fractures (41), in both military and non-military populations. During pregnancy, relaxin and estrogen decrease elasticity in ligaments in the pelvic region and throughout the body (38). By widening the pelvic area, anatomical changes occur to better compensate for the

growing uterus (38), the increased bodily weight (42), and the change in gait patterns (43,44). While the strain on a female's body is immense throughout gestation, the significant hormonal fluctuation regulates itself in lactating females after four to five months, causing joints to stay vulnerable to MSKi during this period of time (39,45).

The literature examining physical fitness and injury potential in the postpartum period is sparse but identifies a critical point for specialized support. Within the US Army population, it was found that females who took their physical fitness test at 6-months postpartum and at 1-year postpartum were more likely to have lower fitness performance scores, indicating a lack of preparedness for returning to active duty (46,47). A study conducted on servicewomen of the British Army, postpartum illness and injury risk were highest between 6-months to a year postpartum, with these female service members being considered physically unprepared for the full active duty required after a year (16). Within the first year postpartum, 75% of female service members in the British Army sustained an MSKi compared to only 21% of their counterparts who had not recently experienced a pregnancy (48). The main body regions that sustained MSKi were, not surprisingly, the lumbopelvic, abdominal, hip, and groin areas (48). It is key to note that over a 6-month period in 2019, female service members in the US Army were found to take 35.4% of their days off from duty due to either pregnancy or postpartum factors (49). These findings demonstrate the critical nature of the antenatal and postpartum period with MSKi risk in female service members.

## *2.2 Physical Performance and Musculoskeletal Injuries*

It is known that low physical performance is a risk factor for increased MSKi in service members globally and in the CAF (8,13,50,51); however, whether female CAF members are affected differently than their male counterparts has yet to be determined. Physical performance

needs to be investigated to understand why female service members appear to be at greater risk of RSI.

Previous lower body injuries in relation to future physical performance has not been thoroughly investigated in military and athletic populations. Female athletes with a history of lower limb injuries were found to have detrimental impacts to their joints (12). Joint laxity, muscular strength, and neuromuscular control are among the negative impacts in females with previous lower body MSKi (52,53). In military service members, knees are one of the main joints that hinder performance in occupational roles, and when re-tested after a year no improvements of hinderance was seen(54). In service members who had experienced prior injuries, poorer physical performance was found in running, jumping, and mobility tests (55). Even though there remains minimal literature between prior MSKi and physical performance, a bi-directional association between physical performance fitness markers and future injuries has been identified as a valid avenue to explore (8,56). Physical fitness tests (e.g., standing long jumps [power], distance runs [endurance and aerobic capacity], squats [strength], and sit-and-reach [flexibility]) are currently used to correlate future MSKi risk in civilian populations (57–60). Yet, assessment of MSKi rates with a wide girth of physical fitness components are seldomly used in military settings.

### *Power*

The standing long jump is a simple test that analyzes the muscular power in the lower limbs of individuals (61). In elite civilian athletes, the standing long jump has been correlated with muscular power, and strength (62). A study in 2017 found a strong relationship between the validated Wingate test and a standing long jump, enabling them to use the minimalist standing

long jump for muscular power indication rather than the more cumbersome Wingate test (63). While being a simple movement, the standing long jump is one of the key tests performed in the US Army Physical Readiness Testing (64). Another study, examining physical fitness testing in the Israeli Defense Force, identified that performance scores of female service members during a single-leg jump was a predictor of future lower extremity MSKi (65). While a single-leg jump is not used in this thesis, it is important to acknowledge that the author's sample was only female service members.

### *Aerobic Capacity*

Running tests with a defined distance are commonly applied to assess physical fitness and performance in military personnel. Maximal oxygen uptake ( $VO_2\text{max}$ ) is estimated through the submaximal running trials (one-to-three-mile runs) in militaries to predict injury rates in recruits and specifically male service members (64–68). Data from both US military (64) and Swiss recruits (8) found lower aerobic fitness as measured by single mile run times and long-distance times were risk factors for lower body overuse injuries.

### *Strength & Flexibility*

As heavy lifting is a common task performed by military personnel, the squat is a helpful proxy-measure of performance and injury risk (67). CAF includes the back squat in a number of physical fitness tests required for specialty trades and courses. A study in 2020 analyzed civilian collegiate athletes with back squat performance, finding that those exhibiting lower squat strengths had a higher likelihood of experiencing lower extremity injuries during the season (59). When looking at the relationship between task-specific movements and squatting, the US military found that lower performance on squat tests was correlated to lower performance in load

carriage tasks in female service members (69). These tasks have also been linked to lower body overuse injuries in female service members (35). Female service members are known on average, to possess 25-30% less muscle mass in their lower body than males, indicating strength should be a consideration for females in the military (69,70). Flexibility in the lower body has also been noted as important for physical performance and injuries in athletic settings (60). Lack of flexibility within the hamstrings can relate to poorer squat performance in civilian athletes and could provide valuable information in military populations with the recognition that flexibility impairment contributes to MSKi, especially RSI (71).

Intrinsic factors such as female reproductive health (5) can contribute to increased rates of MSKi in female service members, extrinsic factors, such as physical performance outcomes that are specific to a military occupation need to be explored further in the female CAF population. Knowing that females are at a greater injury risk, and that RSI contributes to early release and failure to deploy, the assessment of muscular strength, endurance, power, and aerobic capacity may help narrow the knowledge gap around female service members in the CAF.

## Chapter 3 Associations Between Female Reproductive Health and Lower Body Injuries in Female Service Members of the Canadian Armed Forces

### Preamble to Manuscript 1

The manuscript “*Associations Between Female Reproductive Health and Lower Body Injuries in Female Service Members of the Canadian Armed Forces*” is aimed at addressing the first objective of this thesis. Aspects of this chapter are published in part in ‘Puranda, J. L., Silva, D. F. D., Edwards, C. M., Nagpal, T. S., Souza, S. S., Semeniuk, K., & Adamo, K. B. (2023). *Association between Reproductive Health Factors and Musculoskeletal Injuries in Female Canadian Armed Forces Members*. *Journal of Women’s Health*, 32(2), 199–207. <https://doi.org/10.1089/jwh.2021.0647>’ and ‘Edwards, C. M., **Miller, É.**, da Silva, D.F., Puranda, J.L., Souza, S.C.S., Semeniuk, K., Adamo, K.B. (2023). *Does a history of childbirth impact injury prevalence and mental health in female military members?* *Applied Physiology, Nutrition, and Metabolism*. 10.1139/apnm-2023-0028’. This chapter furthers the investigation into musculoskeletal injuries in Canadian Armed Forces service members. The lower body is one of the leading injury location for female service members. This manuscript aimed to highlight and examine lower body specific RSIs reported by female CAF service members and associated reproductive health characteristics.

This article has a chosen audience of stakeholders, and service members within the Canadian Armed Forces.

**Associations Between Female Reproductive Health and Lower Body Injuries in Female  
Service Members of the Canadian Armed Forces**

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## ABSTRACT

**Introduction:** Female service members within the Canadian Armed Forces (CAF) are more likely to medically release due to repetitive strain injuries (RSI) than any other type of musculoskeletal injuries (MSKi). Reproductive health plays a large role in how susceptible females are to injuries. The aim of this study was to investigate associations between female reproductive health characteristics and history of lower body RSI in female service members of the CAF.

**Methods:** Cross-sectional data was collected between September 2020 and February 2021 from active, retired, and medically released female service members (n = 855). The electronic questionnaire, “*Online questionnaire addressing sex-disparities in musculoskeletal injuries, reproductive health and barriers to recruitment and retention in the CAF*”, was given to all consenting participants. A bivariate chi-square analysis was performed, and significant results were put through a binary logistic regression using covariates. Covariates used were body mass index, current age, military rank, perceived physically demanding job.

**Results:** Irregular menstruation was significantly associated with previous hip, knee, lower leg RSI (aOR= 2.125; CI (1.430, 3.158); p < 0.001, aOR: 1.584; CI: (1.097, 2.285); p = 0.014, aOR = 1.741; CI: (1.153, 2.630); p = 0.008), having given birth linked to foot RSI (aOR = 1.648; CI: (1.148, 2.364); p = 0.007)

**Conclusion:** Reproductive health is key to understanding lower body RSI rates in female service members.

## INTRODUCTION

Musculoskeletal injuries (MSKis) are one of the leading causes of attrition within the Canadian Armed Forces (CAF) (1). MSKis can include damages to ligaments, nerves, and muscles; they can be categorized as: i) repetitive strain injuries (RSI), which occur over time, or ii) acute injuries, which arise from a sudden acute event (2). Within the military, sex-disparities related to MSKi for female services members have been identified as a growing concern (3). Female service members are more likely to report experiencing an RSI and joint pain compared to their male-counterparts (1), and lower limb MSKi were the leading type of injury reported at 44%, with the majority occurring in female service members (3,4). MSKi impacts operational readiness, and while the specific budgetary data is not made public, the financial burden of this impact is not insignificant (5). Therefore, it is crucial to investigate how risk factors distinctive to female service members in the CAF are associated with increased reporting of RSI.

In 2020, our team published a scoping review that explored various risk factors associated with MSKi among the female military population (6). Similar to female athlete populations, the scoping review illustrated that female reproductive health characteristics influenced MSKi among female military members. Evidence indicates that divergence from healthy fluctuations in estrogen (7), progesterone (8), and relaxin (9), impacts risk of injury among female individuals. Moreover, experiencing irregular menstruation has been shown to diminish strength performance (10), and is associated with an increased risk of reporting overall RSI in the CAF (2). While natural hormonal fluctuation during a menstrual cycle is a key biological function for healthy females of reproductive age, many female military members opt to temporarily halt, or alter their regular menstrual cycle, using hormonal birth control (HC) (11). There are a broad range of reasons for the hormonal disruption including to avoid menstruating

during field training exercises, or to simplify operational deployments (12). While the literature is contentious, data from non-military populations and elite athletes who use HC have reported higher rates of previous injuries and increased risks of experiencing future injuries (8). With 34.4% of the United States military (11) and 31% of the British Armed Forces (13) disclosing the use of HC, understanding the role of HC plays in operational and physical readiness may help us to better understand female-centric risks in militaries worldwide. Given the CAF's heavy reliance on lower body strength and endurance during training and testing (14), investigating the impact of HC on lower body RSI is important and needs further examination.

Pregnancy may be a notable reason for attrition within service members due to a variety of physiological and biomechanical changes (6). Key reproductive health hormones, such as relaxin, increases throughout pregnancy, allowing higher laxity of the pelvic floor muscles and associated structures, ideal for labouring. However, the action of relaxin is not targeted, resulting in a secondary effect on ligaments and muscles throughout the body (15). Females within the CAF who had given birth were found to have a higher likelihood of RSI at the foot (16). Female service members have also been found to have a higher likelihood of injury when returning to duty from postpartum, potentially due to insufficient muscular training and lack of preparation for returning to full-time active duty (17). Therefore, the impact of parity status on the reporting of lower body RSI should be investigated in female CAF members.

Currently, female service members make up 16.48% of the CAF, far from the publicised goal of 25% representation by 2026 (18). With the aim to increase representation of females within the CAF, and injuries being a key deterrent to longevity in service, more information is needed to identify areas of concern to a service members health. The objective of this study is to

examine associations between female reproductive characteristics and reporting a history of lower body RSI among female CAF service members.

## METHODS

### *Study Design and Sample*

A retrospective cross-sectional exploratory study was performed as a sub-analysis of a larger study investigating sex-disparities in the CAF related to female health factors, injury rates, and retention in the military. An electronic questionnaire, “Online questionnaire addressing sex-disparities in musculoskeletal injuries, reproductive health and barriers to recruitment and retention in the CAF”, (SurveyMonkey Inc.) was distributed to service members across the CAF between September 2020 and February 2021. This study was approved by the University of Ottawa Research Ethics Board (H-04-19-3442) and all the procedures adopted were in accordance with the Declaration of Helsinki. Inclusion criteria for the larger study were: i) currently serving, or previously serving members of the CAF, ii) aged 18 to 65 at the time of response, iii) voluntarily giving consent to participate, and iv) identified their biological sex. For the sub-analysis, only those who met the following criteria were eligible: (i) responded “female” for biological sex, (ii) reported sustaining a lower body RSI during service.

Methods used to recruit participants included: word of mouth, social media, and internal CAF media channels with a reliance on snowball sampling.

### *Statistical Analysis*

The independent variables examined in the analysis were: menstrual cycle periodicity, use of hormonal birth control, whether the individual had given birth while serving, and age of

menarche. For categorical variables, >20 responses per group was the minimum sample required for analysis. The outcome variables for this sub-analysis were lower body RSI locations (i.e., hip, thigh, knee, lower leg, ankle, foot, toes). All data was self-report, and participants were instructed to only report injuries that occurred during their time “in service”.

For the outcome of reporting an RSI, data was missing at a rate of 19.3%. To address missing data points, we implemented a listwise deletion method for the main outcome variable. After removing missing data points, the analysis remained adequately powered.

Statistical analyses were performed using the SPSS statistical software (SPSS Inc., Chicago, IL, USA). To describe participant characteristics categorical variables were presented using frequency and percentage, while continuous variables were shown using mean and standard deviations (Table 1).

A bivariate association was used to identify associations between the female reproductive health characteristics and lower body RSI location. Chi-square or Fisher’s exact tests were used for 2 x 2 table bivariate associations, and Chi-square test or Likelihood ratio were used for bivariate associations requiring greater than 2x2 tables. Fisher’s exact and Likelihood ratio were implemented when the assumption of <20% of cells, with an expected count of <5, was not met. Associations found between the independent and outcome variables that reached significance ( $p < 0.05$ ), were further analyzed using binary logistic regressions. The covariates chosen for these analyses were: year of enrollment into the CAF, current body mass index (BMI) score (‘underweight and normal weight’, ‘overweight’, and ‘obese’), rank (Non-Commissioned Member or Officer), and whether the individual perceived their occupation as being physically

demanding. Adjusted odds ratios (aOR), and 95% confidence intervals (CI) were presented for each logistic regression.

## RESULTS

A total of 2,253 active and retired service members accessed the survey, and voluntary consent was given by 2,001 participants. Of these respondents, 855 were identified as female participants. There were 657 females who responded to the questions about hormonal birth control use, 656 who responded to the questions about their menstrual cycle, 643 that responded about their age of menarche, and 657 females who responded about having given birth while serving. Descriptive characteristics of the participants can be seen in Table 1.

Bivariate associations between reproductive health characteristics and lower body RSI locations can be found in Table 2. Statistically significant associations were seen between menstrual cycle irregularity and four lower body RSI locations (i.e., hip, knee, lower leg, toes). As well, parous females have statistically higher foot RSI rates than non-parous females.

The lower body RSI locations that are significantly affected by menstrual cycle irregularity and parity status were then used in a binary logistic regression, as shown in Table 3 and Table 4. Only toe RSI was not put through the regression as there was not a large enough sample size to withstand the covariates of the model. The remaining locations remained significantly associated with menstrual cycle irregularity and parous individuals after adjustments of covariates.

Table 1: Participant Demographic Characteristics

<b>Panel A: Participant Characteristics</b>			
<b>Variable</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>Range</b>
Age (yrs)	38.80	9.70	[20, 65]
Height (m)	1.65	0.07	[1.42, 1.86]
Weight (kg)	73.70	14.40	[43.10, 149.70]
BMI (kg/m <sup>2</sup> )	26.90	5.00	[17.20, 48.8]
<b>Panel B: Study Characteristics (N = 855)</b>			
<b>Variable</b>	<b>Frequency (n)</b>	<b>Frequency (%)</b>	
<i>Military Branch</i>			
Canadian Army	384	44.9	
Royal Canadian Air Force	357	41.8	
Royal Canadian Navy	97	11.3	
<i>Parity Status</i>			
Nulliparous	387	45.3	
Parous	270	31.6	
<i>Hormonal Birth Control</i>			
Yes	512	59.9	
No	145	17	
<i>Menstrual regularity</i>			
Yes	381	44.6	
No	275	32.2	
<i>Age of Menarche</i>			
<10 years	554	64.8	
11 - 15 years	49	5.7	
>16 years	40	4.7	

**Note: BMI, body mass index**

Table 2: Chi-Square for Reproductive Health Factors in the CAF Associated with Lower Body RSI

Variable	Hip		Thigh		Knee		Lower Leg		Ankle		Foot		Toes	
	n (%)	Sig.	n (%)	Sig.	n (%)	Sig.	n (%)	Sig.	n (%)	Sig.	n (%)	Sig.	n (%)	Sig.
<i>Hormonal Birth Control</i>														
No (ref)	27 (17.2)	0.08	4 (2.5)	0.77	39 (24.8)	0.23	26 (16.6)	0.31	21 (13.4)	0.10	40 (25.5)	0.09	8 (5.1)	0.63
Yes	119 (23.8)		15 (3.0)		149 (29.8)		101 (20.2)		96 (19.2)		163 (32.6)		21 (4.2)	
<i>Menstrual Regularity</i>														
Yes (ref)	66 (17.3)	<0.001*	8 (2.1)	0.15	93 (24.4)	0.005*	59 (15.5)	0.003*	61 (16.0)	0.15	111 (29.1)	0.20	12 (3.1)	0.04*
No	80 (29.1)		11 (4.0)		95 (34.5)		68 (24.7)		56 (20.4)		93 (33.8)		18 (6.5)	
<i>Given Birth While Serving</i>														
Nulliparous (ref)	84 (21.7)	0.62	11 (2.8)	0.93	116 (30.0)	0.41	72 (18.6)	0.50	64 (16.5)	0.26	97 (25.1)	<0.001*	19 (4.9)	0.61
Primiparous/ Multiparous	63 (23.3)		8 (3.0)		73 (27.0)		56 (20.7)		54 (20.0)		107 (39.6)		11 (4.1)	
<i>Age of Menarche</i>														
11-15 years (ref)	113 (20.4)	0.07	16 (2.9)	0.70	161 (29.1)	0.24	103 (18.6)	0.49	101 (18.2)	0.40	179 (32.3)	0.07	28 (5.1)	0.50
<10 years	13 (26.5)		1 (2.0)		16 (32.7)		12 (24.5)		6 (12.2)		16 (32.7)		1 (2.0)	
> 16 years	14 (35.0)		2 (5.0)		7 (17.5)		6 (15.0)		5 (12.5)		6 (15.0)		1 (2.5)	

Note: n is the frequency. ref is the reference group. Significance (Sig.) is p<0.05 (\*).

Table 3: Binary Logistic Regression for Menstrual Regularity in the CAF with Lower Body RSI

Variable	Hip			Knee			Lower Leg		
	n (%)	AOR (95% CI)	Sig.	n (%)	AOR (95% CI)	Sig.	n (%)	AOR (95% CI)	Sig.
<i>Menstrual Regularity</i>									
Yes (ref)	66 (17.3)	2.125	<0.001*	93 (24.4)	1.584	0.014*	59 (15.5)	1.741	0.008*
No	80 (29.1)	(1.430, 3.158)		95 (34.5)	(1.097, 2.285)		68 (24.7)	(1.153, 2.630)	

Note: Adjusted using the following covariates: BMI, current age, Rank (NCM or Officer), perceived physically demanding job (yes; no). Abbreviations: AOR, Adjusted odds ratio; CI, Confidence interval; Sig., Statistical Significance. \*Significant at  $p < 0.05$ .

Table 4: Binary Logistic Regression for Having Given Birth While Serving in the CAF with Lower Body RSI

Variables	Foot RSI		
	N (%)	AOR (95% CI)	Sig.
<i>Given Birth while Serving</i>			
Nulliparous (ref)	97 (25.1)	1.648 (1.148, 2.364)	0.007*
Primiparous/Multiparous	107 (39.6)		

Note: Adjusted using the following covariates: BMI, current age, Rank (NCM or Officer), perceived physically demanding job (yes; no). Abbreviations: AOR, Adjusted odds ratio; CI, Confidence interval; Sig., Statistical Significance. \*Significant at  $p < 0.05$ .

## DISCUSSION

This study aimed to investigate the associations between female reproductive health characteristics and the history of lower body RSI in female service members in the CAF. The rationale for this study align with the CAF's goal of increasing female representation within the military population; given that active service is primarily during reproductive years. Our results demonstrate a significant association between reproductive health (i.e., menstrual irregularity and parity) and lower body RSI locations in female CAF members.

Menstrual cycles are a naturally occurring component of female reproductive health and support a multitude of systems within the body. Regular menstruation represents a form of homeostasis resulting from coordinated signaling between one's brain (i.e., hypothalamus, pituitary) and ovaries. Irregular menstrual cycles (i.e., amenorrhea) are a sign of system disruption, which can lead to hormonal imbalances with physiological implications. In regular menstruation, estrogen, and progesterone aid in vascular elasticity and vasodilation within the cardiovascular system, and contribute to thermoregulation efficiency (19,20). Hormonal fluctuation that occurs during a regular menstrual cycle also supports muscle development (7), bone health (21), and ligament flexibility (8). Data in the military populations suggests that experiencing amenorrhea is associated with increased reported injuries; a trend that is positively correlated with the duration of irregular menstruation (22). For example, in US female recruits, irregular menstruation is associated with higher rates of stress fractures at the pelvis and femur (11,23). In the CAF, female service members who experience irregular menstruations report higher rates of overall RSI (2). These findings indicate that irregular menstruation negatively affects healthy physiological maintenance, which increases the likelihood of female service members sustaining an RSI. The outcome of this study provides a more localized understanding

of the association between menstrual regularity and RSI may help target the cause of medical releases following a lower body RSI in the CAF. Given the higher rates of RSI at the hip, knee, and lower leg observed in female service members who reported menstrual cycle irregularity, it is possible that bone health, and muscle development are locally impaired by the abnormal hormonal fluctuation.

Our results also showed a significant association between parity and RSI of the foot. These findings may be due to the large physiological, anatomical, and gestational weight changes that occur to a female body during and after pregnancy (24–26). Physiological changes seen throughout gestation include an increase in blood volume that impacts cardiac output and stroke volume (27), while also seeing a significant rise in relaxin throughout the body (15). The surge in relaxin circulating in the body instigates supports the changes seen at the pelvic floor in preparation for labour, while also causing laxity in secondary ligaments and muscles (15). Hip muscles are known to relax and widen to prepare for delivery by relaxin, and, in turn, increase strain on other lower body locations to accommodate for the shift (15). Additionally, lung capacity becomes compromised due to the growing uterus that puts pressure on the internal space of the torso (27). On top of physiological changes, gestational weight gain plays a role in how the female body adjusts and compensates throughout pregnancy. Given the 20 to 40 lbs gained during the gestational period (28), pressure significantly increases on the hip, feet, and lower back joints (24). This weight gain in addition to surges of laxity in the lower body widens the hips, changing the angles of the lower joints, causing for females to change their walking gait and standing postures (26). Future studies should investigate the point in time at which foot RSI are beginning to surface, whether it be during gestation, postpartum, or returning to duty.

There were no significant associations between HC and age of menarche with lower body RSI. With a high prevalence of HC use among female service members worldwide (34%; (12)), with rates of 59.9% in our CAF sample, further investigation on long-term use of these products for the manipulation of menstrual cycles (i.e., halting menstruation) should be examined in the context of injury risk. Future work should monitor the changes in female service members before and during usage of HC to see if there is a change in how the muscles perform, and develop, and how potentially it links to injury prevention or risk. While there are associations between injury prevalence and the use of oral contraceptives in civilian elite athlete populations, more extensive knowledge is needed to understand the effects in the CAF population (8). Given that standardized physical fitness and health requirements are in place for military service, understanding how synthetic hormones impact muscle development and injury risk over time could help with operational readiness.

Strengths of this study include the large sample size ( $n = 2001$ , with females = 855) and the novelty of it being one of the first to investigate specific lower body RSI in relation to reproductive health in solely CAF females. Limitations to this study were primarily the cross-sectional design of the questionnaires. Due to the lack of temporal data on injury status during service, and at what stage of one's reproductive health journey injuries were sustained, causation cannot be established. A life course longitudinal design, where researchers could identify the point during service when injuries are occurring and whether reproductive factors (i.e., pregnancy, or long-term irregular menstruation) are truly the cause of injuries for these service members, would be beneficial for deepening the characterizing of these relationships. The self-reported nature of our injury data is a limitation due to reliance on accuracy of recall. Also, our recruitment method began with a wide range of social media and military platforms then

ultimately relied on snowballing, meaning participants were encouraging or suggesting that their colleagues and peers participate. This is a strength and a limitation as it provided more participants, but participants that were similar in demographics and occupational environments. Other limitations included the lack of consideration for previous physical activity levels, as well as nutritional background. Both categories in literature have shown influence in the likelihood of irregular menstruation, as well as healthy hormonal fluctuation and should be used in future investigations (6).

The results of this study illustrate significant associations between lower body RSI and female reproductive health characteristics. These findings demonstrate key health factors that should be considered with injuries in female service members in the CAF. This study provides a deeper look into where health care providers should aim their attention in injury risks in the future. Future research should evaluate the association between reproductive health and physical performance as it relates to operational readiness, as well as how hormonal changes, natural and synthetic, can impact the longevity of service in the CAF.

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## **Chapter 4 Are Previous Lower Body Repetitive Strain Injuries Linked to Physical Performance Outcomes in Female CAF members?**

### Preamble to Manuscript 2

The manuscript “*Are Previous Lower Body Repetitive Strain Injuries Linked to Physical Performance Outcomes in Female CAF Members*” focuses on Objective 2 of the current thesis, which wished to determine if females with a history of lower body RSI have poorer physical performance than non-injured counterparts. As females stay at higher risks of reporting RSI, especially in the lower body, this investigation looked into how performance was associated with previous RSI.

The article is formatted for submission to the Women in Sport and Physical Activity Journal.

**Are Previous Lower Body Repetitive Strain Injuries Linked to Physical Performance  
Outcomes in Female CAF members?**

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## Abstract

Repetitive strain injuries (RSI) are the top reported musculoskeletal injury (MSKi) reported by Canadian Armed Forces (CAF) service members. This study sought to investigate associations with previous lower body RSI with lower body physical performance in female service members. In-person data was collected from female service members ( $n = 90$ ) who performed 5 lower body physical performance tasks (i.e., sit-and-reach, long jump, 4-repetitive maximum (RM) back squats, single-legged wallsit, treadmill  $VO_{2max}$ ). All participants were given a Health Appraisal Questionnaire to ensure voluntary consent, eligibility, and injury locations. Analysis of Variance (ANOVA) and analysis of covariates (ANCOVA) were used to determine associations between lower body RSI location (i.e., hip, thigh, knee, lower leg, ankle, foot, toes) and the physical performance tasks. Covariates included were irregular menstruation for hip, knee and lower leg RSI locations, and parity for foot RSI. A significant association was found between having reported a previous ankle RSI and higher  $VO_{2max}$  scores ( $p = 0.048$ ). All other lower body RSI locations were not significantly different. All effect sizes (ES) calculated in the analysis are trivial to small ( $ES < 0.5$ ). Overall lower body physical performance of female service members in the CAF is not different in those who had experienced a lower body RSI compared to non-injured counterparts. Those having experienced ankle RSI were found to perform better aerobically. Lower body RSI are not a hinderance to female service members when it comes to physical performance.

**Key Words: Repetitive strain injury, female, military, lower body, performance**

## Introduction

As of 2023, female representation within the Canadian Armed forces (CAF) stands at 16.48% (Government of Canada, 2023), not far off allied military rates (USA 17.3% (States of America Department of Defense, n.d.), United Kingdom Regular Forces 11.3% (Kirk-Wade, 2022)). With the hope of reaching 25% by 2026, risk factors leading to early attrition and sub-optimal recruitment need to be identified within the CAF female service member population (Strauss et al., 2014). A health-survey administered in 2013-2014 by the CAF, identified that 40% of service members were medically released, with repetitive strain injuries (RSI) and joint pain being the leading cause for females (Strauss et al., 2014).

RSI is a category of musculoskeletal injury that occurs due to overuse to the muscles, nerves, ligaments, and/or tendons (Hauret et al., 2010). Within the CAF population, our research team has identified sex-discrepancies when it comes to RSI rates, with females presenting ~40% higher likelihood (aOR: 1.397 [1.068; 1.829]) of reporting RSI than males (da Silva et al., 2023). In addition, more females compared to males perceived that daily activities and career progression were negatively impacted by RSI (da Silva et al., 2023). All members of the CAF are required to maintain a set of competencies, referred to as the 'Universality of Service' (Government of Canada, 2018). The physical attributes of the 'Universality of Service' are assessed using the Fitness for Operational Requirements of Canadian Armed Forces Employment (FORCE) that cover the most common military tasks (Government of Canada, 2018). While the tasks listed are well-rounded for occupational readiness, most tasks demand a notable degree of lower body strength and power, such as 20-metre rushes, sandbag lift, intermittent shuttle runs, and a sandbag drag (Government of Canada, 2018). Previous injuries, whether acute, or RSI, can lead to a decrease in performance and increase an individual's risk for

future injury (Teyhen et al., 2016). Research in civilian athletes suggests that previous hip, elbow, and hand injuries were all risk factors for poor performance on the functional movement screening test that is used commonly to determine physical performance readiness (Chimera et al., 2015). Other studies found that previous knee injuries experienced by recruits and conscripts in global militaries were associated with decreased range of motion in movements and diminishing overall physical performance during service (Larsson et al., 2009; Teyhen et al., 2016). However, these studies highlight the lack of female representation within their sample and note that females should be investigated in more depth due to differing physiological and biomechanical factors.

Our research found greater likelihood of females reporting foot and hip RSI than males in both Canadian Army and Royal Canadian Air Force. In addition, the foot, hip, and knee are among the most prevalent body regions (rates vary from 24.4 to 38.5% depending on the military environment) reported to be impacted by RSI in female CAF members (da Silva et al., 2023). What has yet to be investigated in female CAF members is whether those individuals who self-reported RSI in the lower body would also exhibit lower fitness-related markers, which would be expected due to the link between lower fitness and increased rates of RSI (Molloy et al., 2020; Sammito et al., 2021).

The association between fitness markers and MSKi within military personnel has been well-established in literature, enabling an in-depth prediction of future injuries (Jones & Hauschild, 2015; Lisman et al., 2017.; Molloy et al., 2020; Sammito et al., 2021). Predicting future injuries depends on the type of fitness marker being assessed and how it is used in different environments (De la Motte, et al., 2017a; De la Motte, et al., 2017b; Lisman, et al., 2017). In a three-part systemic review, muscular strength, endurance, and aerobic fitness were

deemed as important markers for injury risk (De la Motte, et al., 2017a; Lisman, et al., 2017), whereas muscular power and flexibility have a moderate level of evidence for prediction of injuries (De la Motte, et al., 2017b). A bi-directional relationship between fitness markers and injuries has been suggested (Lincoln et al., 2002; Sammito et al., 2021); meaning both future and previous injuries, such as RSI, were correlated with lower physical fitness scores on running, jumping, and functional movement screening tests (Teyhen et al., 2016).

Thus, the current study aimed to compare female individuals who have experienced lower body RSI versus those who have not on five lower body physical performance tasks (i.e., sit-and-reach, long jump, back squat, single -leg wall-sit, treadmill maximal oxygen uptake [VO<sub>2</sub>max] test). It is hypothesized that female service members with a previous lower body RSI will perform worse, on average, than non-injured females on all five tasks.

## **Methods**

### *Participants*

The current study is a sub-analysis of a larger project on the CAF and female service members (da Silva et al., 2023). Active female service members were recruited over a five-month span to participate voluntarily in the study at two different sites in Canada: 1) Ottawa (at the University of Ottawa) and 2) Petawawa (Dundonald Hall Fitness, Sports and Aquatic Centre). Recruitment methods involved using various social media avenues, including CAF specific media channels, and was supported by snowball recruitment. Ethics approval from the University of Ottawa Research Ethics Board (H-11-20-6180) was granted for all procedures, and this study follows the Declaration of Helsinki.

The inclusion criteria for the overall and sub-study were: i) being between 18-55 years, ii) being an active member of the CAF, iii) being cleared to engage in maximal exercise, iv) providing informed consent to participate, v) identifying female as their sex, vi) having a previous MSKi. The larger project included female members who self-reported at least one musculoskeletal injury (acute or chronic) during the service period. For the current sub-analysis, we stratified these participants based on their report of hip, thigh, knee, lower leg, ankle, foot, and toe RSI (i.e., Yes or No). Participants were excluded if they identified having any of the following: i) diabetes (of any type), ii) uncontrolled hypertension, iii) untreated thyroid disease, iv) cardiovascular diseases, v) being pregnant, and vi) reported contraindication to exercise. Participants were screened for inclusion and exclusion based on their responses to the Health Appraisal Questionnaire that queried general health, reproductive health, and injury history. This questionnaire was developed by the research team and provided electronically using SurveyMonkey Inc. (San Mateo, USA), and in some cases paper copies.

### *Data Collection*

The independent variables included injury history at seven lower body RSI locations (hip, thigh, knee, lower leg, ankle, foot, and toes) that were collected through self-reporting in the Health Appraisal Questionnaire. Those volunteers meeting inclusion criteria were asked to attend in-person physical sessions.

The in-person assessment session took roughly 180 minutes. Participants were asked to avoid tobacco and consumption of alcoholic drinks eight hours before their trial due to other aspects of the larger study (e.g., body composition assessment, blood draws). Participants were also required to wear clothing suitable for indoor physical fitness activities (i.e., sports top or t-

shirt, shorts, socks, running shoes). The physical tests for the larger study were performed in this order i) sit-and-reach, ii) long-jump, iii) medicine ball throw, iv) 4 repetition-maximum back squat, v) 4 repetition-maximum chest press, vi) Biering-Sorensen test, vii) single-leg wall-sit, viii) push-ups, and a ix) treadmill VO<sub>2</sub>max test.

Below is the description of the tests used to measure the six dependent variables included for this sub-analysis:

### *Flexibility*

The sit-and-reach test was used to estimate flexibility (Afonso et al., 2021; Hoffmann et al., 2019). The test box used was placed against the wall. Participants, with their shoes off, were instructed to sit 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. Once ready participants then leaned forward in a slow and steady movement as far as possible. Participants performed three attempts and the best result is used in the analysis.

### *Muscular power*

The long jump (Krishnan et al., 2017) required individuals to stand at the starting position with their legs parallel and feet shoulder-width apart. Participants were instructed to bend at their knees and bring the arms behind the body. Then, with a powerful drive, they were asked to extend their legs, thrust their arms forward and jump as far forward as possible. The distance used for analysis was the furthest perpendicular distance from the start line to the back of the closest heel.

### *Muscular strength*

Four repetition maximum (RM) back squats (ACSM, 2023) were performed for each participant and was used in the analysis. Participants had 4 attempts for each set of the maximal movements with 3-5 min intervals between them to achieve the maximal weight. Weight progressed by ~10 lbs each set. Participants performed all the 4 repetitions without any help from the testers. Two spotters were provided to provide security (one on each side of the bar) for each repetition.

### *Muscular endurance*

The single-leg wall-sit on both left and right leg were performed (Chimera et al., 2017). Participants were instructed to sit for as long as possible with their back against a wall and their hip and knees at 90° flexion. The time started when one leg (the participant is free to choose which leg they start with first) is lifted from the ground. A minute rest was given between each leg.

### *Aerobic fitness*

Lastly, the VO<sub>2</sub>max test was performed in accordance with the Patrol Pathfinder Course protocol (Laframboise et al., 2018). For the warm-up, wore only the heart rate (HR) monitor (Polar V800, Finland). Participants commenced running on the treadmill at a speed of 4 mph and the speed was increased until they reached a heart rate close to or on 75% of heart rate reserve (HRR) (Canadian Armed Forces, 2018). Following the warm-up, participants were fitted with the breathing apparatus (i.e., facemask and head support from the metabolic gas analyzer; K5 Cosmed, Italy), and a 1–5-minute period in a standing position was used to collect resting metabolic values and confirm if the values were within an expected range for a resting condition

(i.e., 3-6 mL/kg/min). The first 2 minutes of the treadmill test consists of running at an initial grade of 0% and at the speed determined during warm-up. Thereafter, the treadmill incline is increased by 2% every 2 min until a respiratory exchange ratio (RER) of 1.0 is achieved. When an RER value of 1.0 is achieved, the treadmill incline is increased by 1% every minute until volitional fatigue, at which time the test is terminated. At the end of each 2-min test increment, up to when an RER value of 1.0 is achieved, the participants provide a rating of their perceived exertion using the Borg Scale. The validity of the  $\text{VO}_2\text{max}$  values was confirmed if at least two of the three following criteria are achieved: i) measured maximal heart rate within  $\pm 10$  bpm of the predicted maximal heart rate based on Tanaka et al. (2001) equation (Maximal heart rate =  $208 - [0.7 \times \text{age in years}]$ ); ii) rating of perceived exertion  $\geq 18$  in the 6-20 Borg scale; iii) respiratory exchange ratio  $\geq 1.0$  (Tanaka et al., 2001). At any point during the participant was allowed to voluntarily end the test.

### *Statistical Analysis*

Data were analyzed using the SPSS statistical software, version 27 (SPSS Inc., Chicago, Ill, USA). Descriptive analyses involved calculating mean and standard deviation (SD) for continuous data and frequency (absolute and relative) for categorical data. To compare means of physical testing results between female members who reported RSI (for each lower body region) and those who have not reported injury, we used Analysis of Variance (ANOVA). Covariates included in the analysis (i.e., ANCOVA) were female reproductive health factors previously linked with RSI (e.g., irregular menstrual cycle and giving birth while serving) (Puranda et al., 2023; Edwards et al., 2023). We have not tested the normality assumption since ANOVAs are thought to be robust enough to compare means independently of normality results (Blanca et al., 2017). Before performing the ANOVAs and ANCOVAs, the assumption of homogeneity of

covariance was tested and confirmed using Levene's test. Significance was set at  $p < 0.05$  for all statistical analyses.

## **Results**

Participant demographics are illustrated in Table 1. In Table 2, associations between participants who had experienced a lower body RSI and those who had not are outlined with lower body physical performance outcomes (e.g., sit and reach, long jump, etc.). A significant association between participants who reported an ankle RSI and their performance on the VO<sub>2</sub>max test was noted ( $p=0.048$ ). Each association in Table 2 showed trivial or small effect sizes (Cohen-1988-Statistical-Power, 1988).

## Discussion

Injury history and physical performance are two aspects important to any service member's longevity of service. Our findings refute the original hypothesis, which stated that those who had experienced a lower body RSI were more likely to have poorer physical performance than those who had not. The sole significant finding yielded by this analysis is the greater VO<sub>2</sub>max scores for female service members with a history of ankle RSI compared to those having never sustained an ankle RSI. Other than this one counter-intuitive finding in our sample, our data support the null hypothesis; that there is no difference in physical performance between those who have experienced a lower body RSI and those who have not.

Many differing pathophysiology pathways can lead to an RSI. Underuse of a tendon is one of the causes for increased likelihood of RSI occurring (Aicale et al., 2018). Without the physiological stressor or loading that comes from physical training to aid in degradation prevention, individuals are at risk of RSI when applying repetitive forces that the tissue is not accustomed to (Gaida et al., 2009). Evidence also suggests that in tissue identified from a tendinopathy - overuse injury in the tendon - the collagen fibres showed a higher ratio of reparative fibres than normal and consisted of irregular and unequal crimping fibres (stress absorbing fibres) (Aicale et al., 2018; Järvinen et al., 1997; Maffulli et al., 2003). The irregular and crimping fibre type described is commonly found in cases of Achilles tendinopathy, where excessive loading and mechanical breakdown of the tendon from microtraumas are known to occur (Leadbetter, 1992). In bones, the repetition of force with little to no rest increases the osteoclastic activity causing the formation of new bone, yet this increases weak points in the structural integrity, leading to stress fractures after multiple loading sessions (Fuller, 2015). With the multitude of pathways of RSI, there are plenty of unknowns as to the extent of the

healing process and rehabilitation required to stop the cyclical nature of an RSI and how this impacts long term physical performance.

Fitness tests offer a proxy or underlying potential for overall performance. There are many different types of fitness and thus various assessment methodologies. Our study used a variety of assessments related to lower body fitness. The sit-and-reach movement is commonly used to investigate hip and lower back flexibility, as well as hamstring stiffness (De la Motte et al., 2017b). Our results indicating that there is no difference in flexibility between groups irrespective of lower body injury location suggests that females could regain range of motion and flexibility post-injury. Previous studies indicate that muscles lacking compliant musculo-tendinous units, as found in tendinopathy tissues (Aicale et al., 2018), have compromised flexibility and therefore increased risk of future injuries (De la Motte et al., 2017b). Even though we examined RSI, our results align with Maniar et al., who found that flexibility scores were not diminished seven days post hamstring strain (Maniar, et al., 2016) . They emphasize that continuous flexibility training before reporting an injury in individuals helped avoid flexibility loss persisting further than seven-days (Maniar et al., 2016). Notably, swelling associated with an RSI reduces within two weeks, which may be linked with the return of pre-injury flexibility past the seven-day point (Aicale et al., 2018). When comparing those who had and had not previously sustained an injury, Hennessey et al. (1993) found that hamstring flexibility, specifically, was not significantly different. They concluded that standing posture was a better marker for previous hamstring injuries. Studies, unfortunately, show no concrete relationship between flexibility and previous RSIs. Consequently, flexibility is not often prioritized in training programs (Nelson et al., 2005). Yet, in the context of military training, having flexibility

in the hip and lower back is important due to the necessity of reaching equipment and handles within and around military vehicles and should be considered in future fitness interventions.

Muscular power, as assessed by the long jump, was also not significantly different between injury groups (yes/no), nor at any lower body injury location. Our results are in keeping with those from a sample of elite hockey players who used physical performance markers to determine associations with those having experienced previous overuse injuries (Comuk Balci et al., n.d.). RSI injury history did not significantly impact long jump performance in these hockey players. Conversely, male Finnish conscripts with low jump performance were 1.8 times more likely to have a history of lower body overuse injuries (Taanila et al., 2015). The main measurement of the FORCE test in the CAF is the speed in which service members complete a set of tasks, and lower muscular power has been associated with slower overall physical performance times (Government of Canada, 2018; Taanila et al., 2015). Our findings indicate that even though an RSI is due to repetitive burden on muscles, ligaments, tendons, and nerves, female service members were able to perform no different than their uninjured counterparts. While not significantly different between injury groups, using long jump as a measure of muscular power may assist future investigations around the prediction of physical performance post-injury.

Lower body muscular strength, as measured by the back squat, was not different between those reporting a history of RSI vs. not. Operational readiness requirements for all service members includes donning equipment weighing large amounts (24.5 kg) (Osborne et al., 2021), and while not a constant burden to everyday operations, service members are required to be able to sustain this weight at any point in training or deployment (Government of Canada, 2023). Studies examining squat performance in females who had previously experienced lower body

injury indicated that strength, joint laxity, and joint control were compromised (Chimera et al., 2015; Steffen et al., 2008). Even though individuals tend to change their biomechanical movements to avoid increasing strain on the previously injured region (Nyayapati et al., 2022; Papadonikolakis et al., 2003), our previously injured sample performed similarly to their uninjured counterparts. Contributors to our null results may range from the pre-injury fitness, injury timeline, recovery time, or rehabilitation programming. Muscular strength plays an important role in the ability of service members to perform on training and deployments, and our results suggest that experiencing RSI does not necessarily result in decreasing muscular strength. Our results may differ due to our sample of service members being potentially more physically active than the average population sample.

Aerobic capacity was found to be significantly higher in female CAF service members who had previously sustained an ankle RSI than those who had not. The nature of operational readiness in the CAF can put service members at risk for various injuries. Overuse injuries in the ankle are notable (Springer et al., 2016) as, throughout training, service members are required to run and walk for long distances and over uneven terrain as part of their occupational requirements (Roy et al., 2015). Limited range of motion in plantarflexion of the ankle from shortened loading response while marching results in increased impact force (Springer et al., 2016). The repetitive forces recruit muscular activation around the ankle and knee to help stabilize the ankle joint for better protection (Springer et al., 2016). Elite athletes with high aerobic fitness are also at an increased likelihood of experiencing RSI in any location of the lower body due to increased training loads (Hreljac, 2004). While fitness level decreases slightly post injury, athletes were able to regain their level of cardiovascular fitness rapidly (Hreljac, 2004; Watson et al., 2017). Potentially, due to excessive training and higher preinjury aerobic

fitness (Roy et al., 2015), our sample with previous ankle RSI performed significantly better. Our findings support the notion that previous ankle RSI do not preclude one from performing better aerobically than those not reporting ankle RSI. For operational readiness, these results may assist in future steps of investigating overuse ankle injuries in service members in the CAF and the rehabilitation that is being used to maintain an elevated aerobic fitness.

This study possesses various strengths. Ours is one of a few studies examining female service members in the CAF, with a sample size of 90 participants is higher than other referenced literature (Knapik et al., 2001). Investigating solely lower body performance tasks against lower body RSI allowed for a closer examination of the associations (Government of Canada, 2023; Optimizing Operational Physical Fitness (Optimisation de l'aptitude Physique Opérationnelle), 2009). Limitations, of this study include self-selection bias. Participants were recruited mostly from Garrison Petawawa and the Ottawa area, with many of the participants being in similar occupational environments. Due to the limited time frame of the in-person collection, caused by COVID-19 health protocols, a restriction on the type of service members who were able to be recruited may not have been representative of the female makeup of the CAF. The self-reporting of injuries from our participants may have been a limitation due to recall bias. Yet, self-reporting has been validated with injuries in military populations and medical records (Schuh-Renner et al., 2018). Our cross-sectional design restricted the ability to determine a cause-and-effect relationship between variables, and only associations could be presented. Another limitation is our inability to determine injury timeline due to the design of our questionnaire. Unfortunately, we have no identifiers of how long it had been since the injury took place, injury rehabilitation, or when and if they fully recovered fully from their injury, limiting our ability to pinpoint whether it was only the injuries causing the associations or other

factors playing a role. Severity of injury was not available and perhaps would have added a more in-depth categorization of RSI within the participants. Unfortunately, we did not collect temporal data related to reproductive health and thus were unable to account for menstrual cycle during the physical testing. The lack of literature around the female CAF population, effect size was used to better determine the strength and magnitude of the associations.

In conclusion, this study provides somewhat unanticipated information regarding RSI and physical performance in female service members in the CAF. Those having experienced a previous ankle RSI were significantly more likely to have better  $VO_{2max}$  scores than those who had not experienced the same injury. Other body regions and physical performance outcomes were not associated with poorer physical performance, refuting our original hypothesis. Future studies should investigate how the proper amount of training, as well as methods of injury prevention could play a role in lowering lower body RSI.

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## Tables

*Table 1: Participant Demographic Characteristics*

Panel A: Participant Characteristics

Variable	Mean $\pm$ SD	Min - Max
Age	33.8 $\pm$ 7.3	20 - 54
Height (m)	1.65 $\pm$ 0.06	1.5 - 1.78
Weight (Kg)	70.3 $\pm$ 12.0	50.7 - 109.3
BMI (kg/m <sup>2</sup> )	25.7 $\pm$ 4.3	18.2 – 37.0
Years Served	10.8 $\pm$ 7.1	2.0 – 31.8

Panel B: Study Characteristics (N=90)

Variables	Frequency (n)	Frequency (%)
<i>Military Branch</i>		
Canadian Army	25	27.8
Royal Canadian Air Force	2	2.2
Purple Trade	63	70
<i>Parity Status</i>		
Nulliparous	51	56.7
Parous	39	43.3
<i>Impact on Duty</i>		
Never	14	15.6
Rarely	29	32.2
Sometimes	41	45.6
Most of the Times	4	4.4
All of the Times	2	2.2

Note: m- metres, Kg- kilograms, BMI- Body mass index, SD- standard deviation.

Table 2: ANOVA/ANCOVA of Associations Between RSI in the Lower Body, and Lower Body Performance Outcomes.

		Flexibility		Long Jump		Back Squat		Wall Sit (Left)		Wall Sit (Right)		VO <sub>2</sub> max	
		Mean ± S/D	Effect Size	Mean ± S/D	Effect Size	Mean ± S/D	Effect Size	Mean ± S/D	Effect Size	Mean ± S/D	Effect Size	Mean ± S/D	Effect Size
<b>Hip RSI α+</b>													
Yes	37.1 ± 6.2	0.39	157.9 ± 29	0.30	153.3 ± 45	0.04	40.0 ± 29	0.05	37.2 ± 23	0.39	43.0 ± 8.1	0.06	
No	34.1 ± 9.1	(small)	166.1 ± 25	(small)	155.0 ± 35	(trivial)	41.3 ± 26	(trivial)	46.9 ± 27	(small)	43.5 ± 8.7	(trivial)	
<b>Thigh RSI</b>													
Yes	37.4 ± 7.2	0.31	156.4 ± 27	0.27	156.4 ± 52	0.05	43.1 ± 37	0.09	49.4 ± 46	0.18	43.2 ± 13	0.001	
No	35.0 ± 8.3	(small)	163.8 ± 27	(small)	154.1 ± 37	(trivial)	40.2 ± 26	(trivial)	43.0 ± 24	(trivial)	43.3 ± 8.0	(trivial)	
<b>Knee RSI α+</b>													
Yes	35.8 ± 10.2	0.12	158.5 ± 26	0.29	148.4 ± 40	0.25	39.6 ± 28	0.05	40.8 ± 22	0.18	42.0 ± 7.7	0.27	
No	34.8 ± 6.8	(trivial)	166.2 ± 27	(small)	157.9 ± 37	(small)	41.0 ± 26	(trivial)	45.2 ± 28	(trivial)	44.2 ± 8.8	(small)	
<b>Lower Leg RSI α+</b>													
Yes	35.4 ± 11	0.03	162.1 ± 36	0.05	149.1 ± 45	0.16	44.5 ± 33	0.18	49.0 ± 31	0.25	43.7 ± 9.3	0.06	
No	35.1 ± 7.4	(trivial)	163.5 ± 24	(trivial)	155.6 ± 37	(trivial)	39.4 ± 25	(trivial)	42.1 ± 25	(small)	43.2 ± 8.3	(trivial)	
<b>Ankle RSI</b>													
Yes	33.6 ± 11	0.24	167.1 ± 29	0.19	153.3 ± 40	0.04	47.3 ± 33	0.33	49.3 ± 35	0.28	46.2 ± 9.8	0.47*	
No	35.8 ± 7.1	(small)	161.8 ± 26	(trivial)	154.7 ± 38	(trivial)	37.9 ± 24	(small)	41.3 ± 22	(small)	42.1 ± 7.6	(small)	
<b>Foot RSI α^</b>													
Yes	34.6 ± 9.2	0.09	159.3 ± 30	0.20	145.8 ± 35	0.32	43.2 ± 36	0.13	39.9 ± 30	0.19	43.2 ± 7.6	0.02	
No	35.4 ± 7.9	(trivial)	164.8 ± 26	(small)	157.7 ± 40	(small)	39.4 ± 22	(trivial)	44.9 ± 24	(trivial)	43.4 ± 8.9	(trivial)	
<b>Toe RSI</b>													
Yes	36.9 ± 5.7	0.26	165.7 ± 20	0.11	172.5 ± 50	0.43	39.9 ± 16	0.03	35.7 ± 6.9	0.48	41.4 ± 8.5	0.24	
No	35.1 ± 8.4	(small)	163.1 ± 27	(trivial)	153.4 ± 38	(small)	40.5 ± 27	(trivial)	43.9 ± 27	(small)	43.4 ± 8.5	(small)	

Note: One way analysis of Variance (ANOVA), One way analysis of Covariance (ANCOVA(α)). 'S/D' standard deviation. ES effect size (classification): Cohen's D (Cohen, 1988) was used to determine classification group. RSI repetitive strain injury. \* Significance p<0.05. Covariates used were irregular menstruation (+) and parity (^).

## Chapter 5 General Discussion

In 2016, the CAF pledged to increase female representation in the armed forces to 25% by 2026. Many gaps remain around the attrition rates in female service members of the CAF. Investigating factors that contribute to injury-related attrition would help inform CAF leadership, and policy makers to better support injury prevention and retention of females in the CAF. The current thesis worked to answer the following gaps in knowledge: 1) how female-centric reproductive health characteristics relate to previous lower body RSIs, and 2) are previous lower body RSIs associated with physical performance outcomes on lower body tasks (i.e., non-fatiguing power, strength, muscular endurance, and aerobic capacity). In response, novel outcomes from this thesis are that irregular menstruation is associated with the prevalence of RSI at the hip, knee, and lower leg and that parity status is also associated with the increased likelihood of experiencing RSI of the foot.

Given that female members of the CAF sustain more RSI overall than their male peers, and 24.4 to 38.5% being in the hip, foot, or knee, more answers need to be obtained (7). Due to the critical component of menstruation in female health, monitoring and supporting CAF members to reduce the risks of irregular menstrual cycle is recommended. Implementing routine questions pertaining to RED-S, which has been linked to increased likelihood of disruption of menses, and overall reproductive health into medical visits may assist in reducing the risk of lower body RSI susceptibility. Future research is needed to identify factors contributing to irregular menstruation in military service in the CAF.

As we know, pregnancy involves anatomical and physiological changes, understanding how to best assist service members pre-, during, and post-natal is vital to female member

longevity in service. It is recommended that initiatives aimed at monitoring the symptoms related to foot RSI, including tendon and ligament stiffness known to be related to plantar fasciitis and tendinopathy, be considered (75). Research examining the effectiveness of changing or modifying equipment, such as boots, to accommodate the alterations to the foot during pregnancy is suggested. Additionally, providing progressive physical training programs that include modified ruck marches may be beneficial in reducing the risk of injury onset. Ultimately, identifying the contributing factors linked to why parous females are associated with higher rates of foot RSI is needed.

While lower body muscular power, strength, and endurance are not associated with RSI of the lower body, higher aerobic fitness is linked to a history of ankle RSI. Given that post-injury physical performance is lowered due to detraining effects (76), female service members in the CAF contradict this knowledge. Service members may be continuing to train while being injured because of certain fitness requirements for military occupational specialties (7). While females may have higher limitations in physical training compared to male counterparts, the number of days taken off is significantly less (7). Furthermore, severe RSIs may not have been accounted for due to participants opting out of certain tests as a consequence of movement restrictions attributed by these injuries. Diversifying training modalities may assist in reducing the onset of overuse lower body injuries. Additionally, prospective studies may consider different training modalities and their relationship with injury prevalence.

Limitations specific to each study are discussed in detail within the respective chapters. However, some limitations require further noting regarding their impact on the larger scope of this thesis. The “*Online questionnaire addressing sex-disparities in musculoskeletal injuries, reproductive health and barriers to recruitment and retention in the CAF*” was produced by

researchers within the lab for a broader study (7); therefore, no modifications to the questionnaires could be made. Data collection was finished by February 2021, before this thesis was conceived. The cross-sectional design of these studies enables the examination of associations not casual-relationships. Self-reporting was also a strategy used for injury reporting and may have elicited unintentional biased answers to the survey questions. While a pointed limitation, self-reporting has been validated against injury recording in medical records within military populations (77). Furthermore, there may be a lack of generalizability within the sample of the second study. Many individuals included were within the same military environment and do not necessarily represent the entire military distribution. Lastly, time of occurrence, duration, or severity of these components collected for injury or reproductive health factors were not collected. These data would have helped provide a more complete story for what may have been the initiating factor for the RSIs.

Collectively, the findings of this thesis suggest further inquiries are needed to address attrition and retention of females in the CAF. While uncovering that lower extremity RSI are linked to reproductive health, the data also suggests that physical performance is not at risk of being lowered after injury. Subsequent studies should examine what is influencing the increased likelihood of RSIs occurring in female service members. Studies monitoring female reproductive health throughout their career could pinpoint the highest point of injury risk for females in the CAF. Increasing representation of females in the CAF is a monumental mission. Each finding gets us a step closer to improving the understanding of injuries that will lead to females being offered the support required to limit attrition and promote long term service.

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## Appendices

### Academic Accomplishments, and Completed Works

#### *Awards*

Support Our Troops National Scholarship, 2021-2022

Special Merit Scholarship for the Faculty of Health Science, 2021-2022

#### *Abstracts and Conferences*

**Miller, É.**, Edwards, C. M., da Silva, D.F., Puranda, J.L., Semeniuk, K., Adamo, K.B. Associations Between Female Reproductive Health and Lower Body Injuries in Female Service Members in The Canadian Armed Forces. Canadian Institute for Military and Veterans Research, CIMVHR Forum 2022. Halifax, Canada. 2022.

**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.

da Silva, D.F., **Miller, É.**, Aboudlal, M., Semeniuk, K., Adamo, K.B. Investigating the association between SmartMoms Canada app usage and physical activity, sleep and self-reported psychological health markers in pregnant women. Canadian Society for Exercise Physiology, Fredericton, New Brunswick, Canada. 2022

Edwards, C. M., da Silva, D.F., Puranda, J.L., **Miller, É.**, Souza, S.C.S., Nagpal, T.S., Semeniuk, K., Adamo, K.B. Does a history of childbirth impact musculoskeletal injury in female military

members?. Canadian Institute for Military and Veterans Research, CIMVHR Forum 2022  
Halifax, Canada. 2022.

Edwards, C.M., da Silva, D.F., Puranda, J.L., **Miller, É.**, Souza, S.C.S., Nagpal, T.S., Semeniuk, K., Adamo, K.B. 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, London, UK. 2023.

Puranda J.L., Akman, A., Edwards, C.M., da Silva, D.F., Souza, S.C.S., **Miller, É.**, Semeniuk, K., Adamo, K.B. Exploring predictors of bone mineral density at the 1/3<sup>rd</sup> radius position among female Canadian Armed Forces members. Canadian Society for Exercise Physiology, Calgary, Canada. 2023.

#### *Publications*

da Silva, D. F., Edwards, C. M., Puranda, J. L., **Miller, É.**, Semeniuk, K., & Adamo, K. B. (2023). Sex disparities in self-reported musculoskeletal injuries in the Canadian Armed Forces. *Applied Physiology, Nutrition, and Metabolism*, 48(10), 757-770.  
<https://doi.org/10.1139/apnm-2023-0029>

Edwards, C. M., **Miller, É.**, da Silva, D.F., Puranda, J.L., Souza, S.C.S., Semeniuk, K., Adamo, K.B. (2023). Does a history of childbirth impact injury prevalence and mental health in female military members? *Applied Physiology, Nutrition, and Metabolism*. 10.1139/apnm-2023-0028

Edwards, C.M., da Silva, D.F., Puranda, J.L., **Miller, É.**, 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?* British Journal of Medicine. (Submitted for review, 2023).

Edwards, C.M., Puranda, J.L., **Miller, É**, Abdoulal, M., O'Rourke, N., MacDonald, M.L.,  
Adamo, K.B. *Musculoskeletal Injuries, Exercise Behaviour, and Reproductive Health as  
Predictors of Physical Fitness of Female First Responders and Health Care Providers.*  
(Submitted for review, 2023).