An Exploration of Musculoskeletal Injuries Occurring in a Canadian Police Agency: Can Fitness Test Results Predict Injury Risk?

by

Liana M. Lentz

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Public Health

School of Public Health
University of Alberta

Abstract

Background Police officers have a greater risk of injury compared to those in most other occupations. A police officer who suffers an injury may not be able to act in their full capacity while they recover resulting in sick time, decreased productivity, limited physical ability, or the development of chronic or comorbid injury. If a police organization has members who are unable to work or perform their regular duties, members of the community may be affected by decreased service, increased response time to emergencies, and increased cost of maintaining services.

Purpose There is little information in the literature regarding police officer injury occurrence. Even less research exists exploring the relationship between physical fitness and musculoskeletal injury in this occupational group. This thesis aims to: 1) review existing literature examining occupational injury in first responders, 2) Systematically review existing literature examining the relationship between fitness and injury in first responders, 3) to analyze injury data from a municipal police service in Western Canada in order to quantify injury prevalence and identify the most common MSI experienced by police officers and 4) to investigate the risk of injury and fitness test performance to identify whether different components of fitness have differing relationships to injury.

Methods Using existing administrative medical and fitness data, this thesis investigates reported musculoskeletal injuries (MSI) that occurred between January 1, 2013 and June 2, 2016 in a cohort of municipal police officers, in a single police service in Western Canada. The injuries could have occurred at or away from work.

Results Over 41 months, the cumulative incidence was 106 injuries per 1,000 personnel, per year. Most injuries were diagnosed as sprains/strains (89.2%) and fractures (8.3%). The back, shoulder, and leg (or lower extremity) were most frequently injured. A multivariate model was constructed using conditional logistic regression to identify what fitness test scores may be used to estimate injury risk. A multivariate conditional logistic regression indicated that a

combination of decreased age, female sex, decreased number of pullups, and increased VO_{2max} best explained increased injury risk. Additionally, the findings indicated an interaction between sex and VO_{2max} so the effect of VO_{2max} on injury risk cannot be understood without accounting for sex.

Conclusions Police officers frequently suffer MSI with sprains and strains the most dominate injury type. The lower extremity, back, and/or shoulder are most commonly injured in this population. Females an older police officers may be at increased risk of injury in this population. Further research should examine sex specific relationships between fitness test scores and injury risk in this population.

Preface

This thesis is an original work by Liana Lentz. The research project, of which this thesis is part, received research ethics approval from the University of Alberta Health Research Ethics Board.

Chapter 3 of this thesis has been published as: Lentz L, Randall JR, Gross DP, Senthilselvan A, Voaklander D. The relationship between physical fitness and occupational injury in emergency responders: A systematic review. Am J Ind Med [Internet]. 2019;62(1):3–13. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22929.

Miss Lentz was responsible for the literature search and the initial review of title and abstracts of the articles. Dr. Randall and Miss Lentz determined the inclusion and exclusion criteria for the articles to be included in the systematic review, assessed study quality and extracted data from the articles. Miss Lentz wrote the original draft of the manuscript which was reviewed and edited but Dr. Randall, Dr. Guptill, Dr. Gross, Dr. Senthilselvan and Dr. Voaklander.

Chapter 4 of this thesis has been published as: Lentz L, Voaklander D, Gross DP, Guptill CA, Senthilselvan A. A description of musculoskeletal injuries in a Canadian police service: Int J Occup Med Environ Health. 2020;33(1):1 – 8. Available from: https://doi.org/10.13075/ijomeh.1896.01454.

Miss Lentz and Dr. Voaklander conceived and designed the concept of the research study. Miss Lentz analyzed the data and drafted the manuscript which was reviewed by all other authors who offered revision suggestions. All authors reviewed the manuscript and gave final approval for the version to be submitted for publication. Miss Lentz, Dr. Senthilselvan, and Dr. Voaklander contributed to methodology. The original draft was written by Ms. Lentz. All authors listed in the bibliographic information contributed to reviewing and editing the article.

Chapter 5 has been published as: Lentz L, Randall JR, Guptill CA, Gross DP, Senthilselvan A, Voaklander D. The association between fitness test scores and musculoskeletal injury in Police officers. Int. J. Environ. Res. Public Health 2019, 16(23), 4667; https://doi.org/10.3390/ijerph16234667 - 23 Nov 2019.

Miss Lentz and Dr. Voaklander conceived and designed the concept of the research study. Miss Lentz analyzed the data and drafted the manuscript which was reviewed by all the other authors who offered revision suggestions. All authors reviewed the manuscript and gave final approval for the version to be submitted for publication. Miss Lentz, Dr. Senthilselvan, Dr. Randall and Dr. Voaklander contributed to methodology. The original drafts were written by Ms. Lentz. All authors listed in the bibliographic information contributed to reviewing and editing the article.

Dedication

This thesis is dedicated to all police officers who work to make their community a better and safer place to live. They have a challenging and dangerous job that is often thankless, but they continue to do their duty even though it is often made obvious that they are not wanted by the people they encounter. It is difficult for them to see that most of the community appreciate their service. I am honoured to have been one of you for so many years. I will continue to consider you friends and work to keep you safe and healthy as best I can.

Contents

Table of Tables

Table of Figures

Acknowledgements

I would like to thank Dr. Voaklander for accepting me as his student and guiding me throughout this PhD process. His support, patience and feedback is greatly appreciated as is his understanding of the academic, personal and professional struggles I encountered along this journey. I would also like to thank Dr. Gross for his detail-oriented perspective, keen revision skills and connecting me with other researchers who have a passion for the wellness of public safety personnel. I thank Dr. Senthilselvan for his kindness and extreme patience for my slow take up of biostatistics. I often wonder who, during this process was more frustrated with me, he or I. Thank you to Dr. Guptill for your pleasantness and alternate perspectives. Finally, thank you to Dr. Randall for answering your office door to answer my statistical software questions when I failed to find the answers to my questions on my own.

I thank my parents for their life-long support and always encouraging to always do my best.

To my friends, thank you for your support and encouragement and keeping me continually accountable by asking me “are you a doctor yet?” and “have you finished your paper?”

Chapter 1: Introduction

1.1 Overview

There are currently very few studies examining the relationship between physical fitness and musculoskeletal injuries (MSI) in police officers. The limited research that does exist indicates that police officers that exercise regularly were less likely to suffer an injury and those with a healthy body composition missed fewer days of work after an injury compared to those officers who were obese (17). This thesis will use administrative data from a municipal police service in Western Canada to quantify injury prevalence and identify the most common MSI experienced by police officers. The second purpose of this study will investigate the relationship between scores on several fitness tests and musculoskeletal injury in this group of municipal police officers. We will investigate the risk of injury in relation to fitness test performance to identify how different components of fitness relate to injury risk.

1.2 Statement of the Problem

Police officers suffer from MSI more frequently than those in most other occupations (1,2) which makes it an important public health problem because having police officers absent from work affects the safety of the community. Research examining the relationship between physical fitness test scores and the occurrence of work-related MSI in police officers is very inadequate. In a recent systematic review, only 4 studies examining the relationship between fitness and injury in police officers were identified (3). Therefore, evidence of relationships between many aspects of physical fitness and occupational injury is limited.

Musculoskeletal injury will be the term used in this thesis and will include sprains, strains, fractures, dislocations, cartilage damage and non-specific joint pain. Psychological injury, catastrophic physical injury, death and homicide will not be included.

1.3 Objectives

This thesis investigates the occurrence of musculoskeletal injuries and the relationship between these MSI and physical fitness test scores in municipal police officers from a single agency in Western Canada. Chapter 3 is a literature review that systematically reviews existing literature examining the relationship between fitness and occupational injury in first responders (firefighters, police officers and paramedics). Chapter 4 outlines a descriptive study that used administrative injury data to quantify injury prevalence and identify common musculoskeletal (MSI) injuries that occurred between January 1, 2013 and June 2, 2016 in a cohort of municipal police officers from a municipal police service in Western Canada. Chapter 5 investigates the relationship between the scores on several fitness field tests, which are completed annually, and musculoskeletal injury in the same group of municipal police officers. Completion of annual fitness test is mandatory for all active police officers up to the age of 45 years. Officers may be exempt from participating in some or all of the field tests if they are injured. The fitness test scores were analysed as continuous variables. The main hypothesis is that the mean scores on fitness tests will differ between injured and uninjured police officers. The risk of injury will be investigated regarding fitness tests in attempt to identify if different components of fitness have differing relationships to injury.

1.4 Significance

The significance of this thesis is that there are limited studies investigating the relationship between physical fitness and MSI in police officers. This thesis looks to increase the knowledge around the epidemiology of police officer injury and the relationship between the occurrence of injury and physical fitness. Additionally, new information regarding sex differences in injury risk in relation to relative VO_{2max} (ml/kg/min) was found which lends direction to future research. Finally, recommendations for injury prevention will be made.

Chapter 2: Literature Review

2.1. Introduction

Duties and responsibilities of a police officer include preventing crime, apprehending those to be taken into custody and fostering a cooperative relationship with the community. Police officers work 24 hours a day, 7 days a week in every community and municipality in Canada (4). Police work responsibilities come with the opportunity to interact daily with a variety of people and situations, whether invited or not, exposing them to a wide range of risks. In 2015, police officers in the United States (U.S.) interacted with 21% of the total population (5). Unlike most other occupations, police officers respond to hostile and dynamic situations that inherently put them at increased risk for injury. The general nature of police work puts police officers at increased risk for physical injury and this presents a public health problem. Police officer absence due to injury has several effects on the community including increased response time to emergencies, decreased availability of services, and increased public costs.

Much research has been done in relation to police officer occupational health and safety in regard to fatigue (6), catastrophic or fatal injury (7,8), and use of force technologies (baton, oleoresin capsaicin spray, conductive energy device) (9–11). However, most of the research concerning use of force is related to the safety and occurrence of injury regarding citizens rather than police officers. There is a paucity of research investigating the incidence of less severe, but more common, musculoskeletal injuries incurred by police officers during daily duties and training. Previously, research investigating police officer homicide or accidental death have also been prevalent however, policing has become physically safer in more recent years (12). Currently, the focus has shifted where much current research examining officer injury relates to psychological injury (13). Though this is a very important area of research, the importance of musculoskeletal injury research in this population is also required in order to gain further understanding of police officer health. The combination of these areas of focus can inform policy makers and police agencies regarding a wholistic overview of the current state of police health and aid in policy and program development designed to keep members of police organizations safe and healthy.

This literature review aims to provide an overview of existing information regarding musculoskeletal injuries incurred by police officers and to identify knowledge gaps where further research is required. Research included in this review has varied definitions of musculoskeletal injury. For our purpose, musculoskeletal injuries will include sprains, strains, fractures, dislocations, cartilage damage and non-specific regional pain (i.e. knee pain, back pain, etc.). In order to have an explicit focus, research regarding psychological injury, catastrophic physical injury, death and homicide have been excluded.

2.2 Public Safety Personnel

Occupational injury to public safety personnel, including police officers, firefighters, and paramedics, is a public health problem affecting both civilians and emergency responders. Between 2004 and 2012, the claims rate for public safety personnel within Australia's national workers' compensation system was 2.6 times greater than all other occupations (2). On average in the USA, police have higher injury rates compared to firefighters (14). Injury prevalence between paramedics, firefighters, and police from an unidentified municipality were compared, from January 1, 2005 to May 31, 2007, and police injury accounted for 48% of all public safety personnel injuries, while fire and EMS accounted for 36% and 18% of the total injuries respectively (15). A police officer being injured during assaults or violent acts (14) that result in traumatic injuries account for the majority of police injury claims in Canada (4). Injury reports from the Milwaukee (Wisconsin) Police Department indicate that the largest proportion of injury incidents occur as a result of use of force while apprehending a suspect accounting for 39%-42% of all officer injuries (16). This differs from firefighters in that the majority of firefighter injuries occur as a result of falls, fire, or explosion (14).

2.3 Implications

Why should seemingly minor injuries such as sprains, strains, and fractures warrant attention? When a police officer becomes injured, the individual may suffer a comorbid injury, or the injury may become chronic. An injury may lead to increased time off work and further medical treatment which increases the total cost of the injury to the employer.

For a police agency, one important implication of injuries and creating a culture of health and safety, is the financial burden associated with injured officers. Costs can be reflected in lost time, overtime pay for a replacement worker, and costs of medical care. One study reported that days off work due to a single injury occurred in 13-15% of police officers who reported being injured, and the average amount of time off work was 5.8 days. In addition, the average number of days off taken for injury rehabilitation was 4.7 (17). Further, an officer may return to work but may not be working in full capacity. A critical review examining research on police officers from multiple countries indicated that the median number of injuries for police officers is 590 per 1000 police officers per year (18). With the average police salary in Canada in 2018 being $99,298, the cost of 5 days of paid leave and a replacement for a single, absent police officer is approximately $5000. In an agency of 2000 police officers, the cost of absence because of injury could cost close to $600,000 per year without accounting for time off for rehabilitation and reduced productivity costs. Because of the high financial burden, police agencies have begun to monitor injuries in the organization, analyze how the injuries occur and to whom the injuries are happening. Using this data, injury prevention initiatives can be developed.

Research indicates that injury rates among police officers vary between 240 per 1,000 personnel per year (19) up to 2,500 injuries per 1,000 personnel /per year (16,21–23). The variance in incidence rates is likely due to varied definitions of injury and various sources of injury data in the literature with studies exploring workers' compensation claims or injuries requiring medical treatment reporting smaller incidence rates likely because this data captures the more serious injuries that occur. Injuries account for many incidents and because of the limited research focus, little is known about the rate of minor injuries and the impact these more common injuries may have on a police organization.

2.4 Officer Safety

In the course of their regular work duties, police are very likely to encounter uncertainty and/or violence so training involves learning to quickly assess dynamic situations and to act to maintain control (11,24). With these responsibilities comes the authority to apply force when circumstances require it. When applied appropriately this represents an essential element in maintaining order in society (25). Low levels of force, such as physical control or empty handed control, are most common in use of force situations and can account for over 50%-80% of use of force occurrences (9). This would likely occur during the arrest of a suspect where the suspect may pull away, resist, flee or become assaultive. Interactions such as this have been found to be the primary cause of all police injuries (14,16,23,26).

Assaults and violent acts accounted for 26%, and bodily exertion for 19% of recorded injuries (14). Officers are more likely to be injured as the subjects' resistance increases (10) so it is important to have effective and safe tools on an officer's duty belt that can be used to subdue physical resistance as efficiently as possible, minimizing the likelihood of police or community members becoming injured.

Force options that can be resorted to in such circumstances always include police presence and communication but, in the event that these are not effective in diffusing a situation, police will use their hands and body and/or intermediate weapons (27). Intermediate weapons include oleoresin capsaicin (OC) spray, batons and conductive energy devices (CED). Police officers were half as likely to be injured during use of force events when a CED was used rather than an empty hand, OC spray, or a baton (10). Research has also concluded that there was reduced likelihood of injury, to both the police officer and the subject, when a CED was used over hands alone as long as no other weapon was used (10,24,28).

There are several other factors associated with the likelihood of an officer getting injured. Police officers in their first 5 years of service or who are overweight (e.g. have greater fat mass) are more likely to be injured in the course of duty (17). During a one year study of multiple police agencies in the USA, approximately 40% of all injuries involved members with 1-5 years of service (17). This could be due to several factors. Police officers in this range of service time and are most likely to be a patrol officer. A patrol officer works in the community responding to calls for service, conducting traffic enforcement, and preventing crime. This lends to increased exposure to suspects and thereby suspect resistance which in turn creates greater likelihood of injury (29–31). Age may also play a role as there seems to be a trend, when adjusted for unit assignment, where injury rates decrease with age (31). There is also suggestion that physical fitness may decrease in the first two years of service and then exceed entry levels by the third year of service (32). Thus, physical fitness may also be an important explanatory factor in relation to occupational injury of law enforcement officers in the first 5 years of service.

The literature makes it quite clear that the most frequent injuries suffered by police officers are musculoskeletal in nature. These injuries include sprains, strains, fractures and other muscle pain (14,16,23,26) incurred primarily through bodily reaction, exertion and violent acts (23%) (4). Injury mechanism is often accidental, and related to suspect apprehension and/or resistance (14,16,22).

2.5 Body part injured

Many sprain/strain injuries occur in relation to apprehending a suspect, whether it is the physical dynamics that occur when a police officer attempts to gain physical control of, or as a result of chasing after, a suspect. This may be due to foot pursuits often ending in confrontation and suspect resistance.

The three most common anatomical areas reported by police officers as being injured are the upper extremities, lower extremities and the trunk (4). However, there is some inconsistency in existing research regarding the most commonly injured area of the body. In general, it appears that police officers injure upper extremities more frequently than lower extremities (31,33). More specifically, research indicates the hand, wrists and fingers are injured frequently (17-21%)(14,31). However, other research states that the back (34,35), shoulder (20), and leg (or lower extremity)(14,21) are most frequently injured. These differences could be related to methods used in the studies. Interestingly, the studies that used workers' compensation data indicated that the upper extremities were injured most frequently (31,33). When data from medical records were analyzed, the lower extremities and back (14,21,34) and the shoulder (36) were more commonly injured. Though not always indicated, it does seem as though the lower back is also a concern for law enforcement occupational injury (34) and lower back pain in police officers has been found to be associated with more time spent driving (35). It is unclear why, but research on back injury appears to be reported separately from other musculoskeletal injuries so it is difficult to compare occurrence measures.

Law enforcement personnel may be at increased risk of lower back injuries due to the nature of their work or physical capabilities. This includes long hours of driving, dynamic interaction with suspects, the burden of a heavy duty belt, and/or some aspect of physical fitness that may be lacking (35,37,38). An interview survey of rural police in the United Kingdom compared two groups that differed in respect to levels of exposure to driving in order to investigate how the amount of driving effected sick time and the prevalence of musculoskeletal injuries. Officers that drove for the majority of their shift when compared to officers who primarily sat, stood, or lifted during the workday, reported having more low-back problems both in general and over the previous 12-month period. Age range and distribution between the groups were similar though years of service as a police officer were not considered. It appeared that the officers in the study group, who were all traffic specialists, had a minimum of 5-6 years of service. The control group could have then had somewhat less time in the profession as they were general patrol members responding to emergency calls and a variety of general policing duties. It is likely that the control group had more interaction with the public and increased likelihood of dealing with suspects than the traffic officers. Despite this possible confounder, traffic officers had similar 12-month prevalence of back problems (65% vs. 66%) compared to general patrol officers. Removing accidental back injury (i.e. acute back pain), the data indicates that 29% of traffic members and 15% or general duty members reported having back problems. In this respect, traffic members may have more chronic back pain compared to general duty members. The authors attribute this difference to mileage driven, with increased mileage associated with increased back trouble. They also indicate that having had a previous "back accident" contributed to a greater amount of sick time taken. Weight was also noted as a possible contributing factor in predicting the number of days absent from work with back trouble. This cross-sectional survey design is limiting as neither lends to predicting back injury in police officers nor sick time that might be taken due to back problems. The authors recommend that prospective studies would yield more valid information but the observation time required for low back trouble to develop makes such a study very expensive and time consuming (35). Other variables that could have been considered but were not, are number of years as a police officer and whether a back injury had occurred prior to, and perhaps leading to, a move to a specialized traffic division. An officer suffering from chronic back pain may seek out a seemingly safer position that would require less dynamic physical interaction with suspects, such as traffic enforcement. Also, one might want to compare differences in police equipment and back injury in order to see if the duty belt and/or body armor play a role in the development of lower back pain.

When the effect of the police duty belt and the type of seat used in a police car were examined, drive time as a risk factor for lower back pain was supported (39). Officers not only spend a lot of time driving in a vehicle, but increasingly are spending time writing reports on the mobile workstation that is in the vehicle. Position of the workstation can create an awkward sitting position that can contribute to an increase in lower back discomfort. In addition to driving, over 13% of a police officer's shift can be spent using the in-vehicle computer and when time taken to write reports in the vehicle is added this accounts for almost 34% of a shift (39). With personal selection of the position of the mobile work station, officers were able to alleviate some of their discomfort (40). In a two session protocol that compared two different seat designs using a randomized arrangement of duty belt equipment, removing or changing location of some equipment on the duty belt improved lumbar positioning and subsequently improved comfort (41). However, the reduced duty belt as used in this study is likely impractical for most patrol officers as several tools necessary for the job were removed including a flashlight and portable radio.

A lack of general fitness may play a role in experiencing back pain. Increased physical activity or physical fitness has been associated with decreased injury in police officers (37). More specifically, those with a body mass index (BMI) greater than 35 were 3 times more likely to report back pain (OR 3.36, 95% CI 1.17-9.66) than those whose BMI fell in the normal range (18-25). Additionally, officers who reported themselves having a high fitness level were less likely to experience back pain (OR 0.48, 95% CI 0.09-0.88) and one third as likely to report back pain (OR 0.37, 95% CI 0.10-0.73) compared to those who reported themselves as less fit. This cross-sectional study may be a good building block for future longitudinal research regarding the relationship between health, fitness and lumbar pain (37).

The relationships between back injury, movement quality and fitness were examined by McGill *et al.* using seven of the tests that comprise the Functional Movement Screen (FMS). In addition, thirteen movements chosen to reflect tasks often used by clinicians to evaluate injury risk were included and involved core muscle endurance tests, hip range of motion tests, and other movement competence tasks. This study concluded that a substantial variance in back injury incidence was explained by lack of torso extensor muscle endurance, hip motion asymmetry and pelvic flexibility. It was also found that increased abdominal endurance as measured by static sit-up posture, front plank, side plank and Biering-Sorensen tests was linked with lower back injury. The major conclusions of this study were that there may be an optimal level of fitness for injury resilience and the model developed was better at predicting those who did *not* sustain back injury (38).

Time of day and position in shift rotation have also been found to have an association with injury (29). The effects of shift work in relation to occupational health and safety have been studied in many areas of work. In Canada, workers on a rotating shift schedule, in different occupations, were found to be at greater risk of a work-related injury. The increased risk was 14.4% for females and 8.2% for men (42). Specific to police, similar concerns have been considered (6). Results indicate that most injuries occur during night shifts with incidence rates more than double when compared to day shift (29,30). These studies did not account for call volume, which could be a confounder as criminal activity is likely higher at night than during the day. The type of call for service may also vary from day to night. An interesting observation has suggested that injuries are more likely to occur during the first few hours of a shift or the first one to two days of the work week (43).

2.6. Prevention

There are modifiable and non-modifiable elements that compose the multifactorial cause of injury in police work. Things like officer safety training and fitness levels are both modifiable and improving these factors may reduce the number of musculoskeletal injuries suffered by police officers. Officer safety training is most often focused on and officers are provided with the tools necessary to protect themselves and the public. Though there is some interest in the effects of physical fitness in relation to officer injury, little has been done to study the effects of improved fitness on musculoskeletal injury rates in law enforcement organizations. Further research is necessary in this area in order to gain a better understanding of the relationship between muscular strength, functional movement, and endurance in relation to police officer injury. The abundance of this type of research regarding sport should support this type of research. Though police officers are not necessarily athletes, their occupation requires that they require dynamic physical movement and physical contact like athletes. This would warrant similar physical training as that required by athletes to improve performance and decrease likelihood of injury. Since police deal with a great deal of violence and unpredictable behavior that increases their probability of injury, and even death, modifying any risk factors of injury should be of utmost importance.

Chapter 3: The relationship between physical fitness and occupational injury in emergency responders:

A systematic review

This chapter has been published as: Lentz L, Randall JR, Gross DP, Senthilselvan A, Voaklander D. The relationship between physical fitness and occupational injury in emergency responders: A systematic review. Am J Ind Med [Internet]. 2019;62(1):3–13. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22929.

Miss Lentz was responsible for the literature search and the initial review of title and abstracts of the articles. Dr. Randall and Miss Lentz determined the inclusion and exclusion criteria for the articles to be included in the systematic review, assessed study quality and extracted data from the articles. I wrote the original draft of the manuscript which was reviewed and edited but Dr. Randall, Dr. Guptill, Dr. Gross, Dr. Senthilselvan and Dr. Voaklander.

3.1. Introduction

Emergency responders – including police officers, firefighters, paramedics, and emergency medical technicians – respond to dynamic situations that can be physically awkward and demanding, thereby putting them at risk for injury. Research indicates that firefighters have an occupational injury rate 3-7 times greater than the national average (2,14,44) and one study indicates that police have a 10% greater occurrence of all injuries compared to firefighters (15). Further, because of physical demands an emergency responder with a seemingly minor injury may not be able to perform regular duties and be required to take days off work or be put on modified duties. In 2014, among police officers, the rate of nonfatal occupational injuries and illnesses requiring time off work was 485.8 cases per 10,000 full-time workers compared to 107.1 per 10,000 full-time workers across all occupations (5). Evidence has shown that police officers who suffer an injury report an average of 4.5 days off per incident with an average additional rehabilitation period of 3.5 days (45). The time away from work would also increase when an organization does not have modified work duties available to accommodate the needs of injured workers.

Military personnel have often been the subject of research investigating the relationship between fitness and injury. This research indicates that increased aerobic fitness is a protective factor for injury occurrence (46,47). For example, a slower unweighted shuttle run time was related to an increased likelihood of both overall and overuse injury in US Army Brigade Combat Soldiers. Comparing the lowest and highest quartile times, participants in the lowest quartile were at twice the risk for both overall injury (OR 1.91, 95% CI: 1.25, 2.93) and overuse injury (OR 2.07, 95% CI: 1.22, 3.49) (46). Teyhen *et al.* also found that, in a group of elite soldiers, a decreased 2-mile run time was a factor for increased risk of injury (47).

A previous systematic review involving military personnel as participants explored the risk factors for injury during basic combat training of U.S Army soldiers. It concluded that factors such as older age at recruitment, history of smoking, and a self-rated low level of physical activity translated to increased likelihood of injury among trainees (48). To the best of our knowledge, no systematic reviews have explored the relationship between physical fitness and injury risk in emergency responders.

The objective of this study is to systematically review existing literature that examines the relationship between physical fitness and the occurrence of work-related musculoskeletal injury in emergency responders including firefighters, police officers, and Emergency Medical Services members (EMS). Existing studies will be described with the aim of identifying the strength of current knowledge, identifying gaps in knowledge, and making recommendations for future research. The commonality of the duties of police officers, firefighters, and emergency services personnel is the response to stressful and dynamic situations that require physically demanding tasks. In addition, the association between different components of fitness (self-reported fitness, strength, flexibility, muscular, and aerobic endurance) and injury will be explored to determine to which of these factors influence the likelihood of future injury.

3.2. Materials and Methods

3.2.1. Search Strategy

A literature search was conducted on April 9, 2018 using databases including MEDLINE, SportDiscus, CINAHL, EMBASE, and Google Scholar. The following search terms were developed with the assistance of a research librarian and were used for the database search: *firefighter, police, emergency responder, paramedic, EMS, injury,* and *fitness*. An additional manual search was performed across the reference lists of selected articles that met the inclusion criteria.

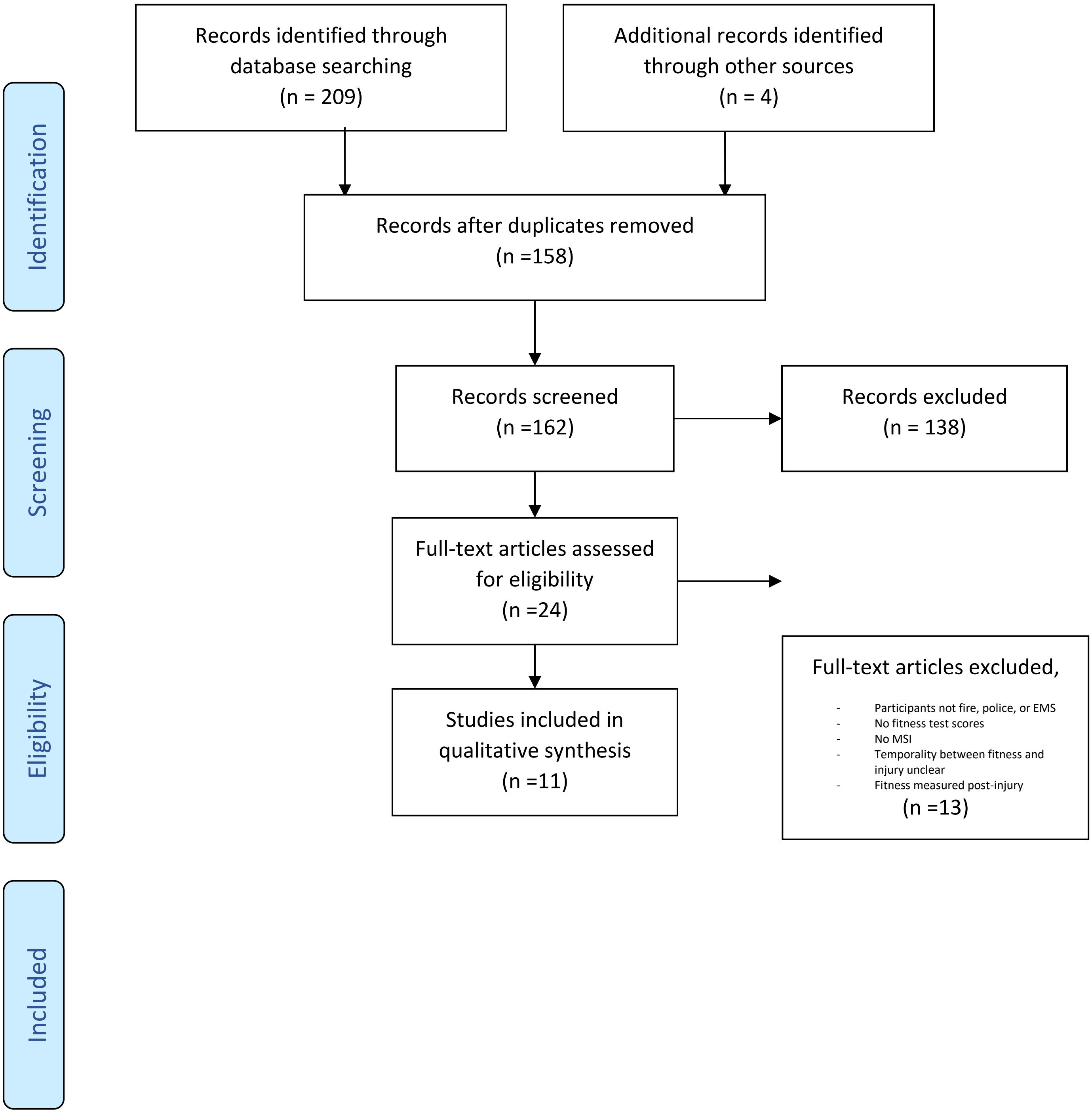
3.2.2. Inclusion Criteria

Two independent reviewers (LL and JR) identified and selected original studies investigating the relationship between musculoskeletal injuries and fitness test scores/levels published in peer-reviewed journals with no specified limit for publication dates. Included studies had to meet the following specific inclusion criteria: (1) The study population was an occupational cohort including active emergency responders (firefighter, police, ambulance worker); (2) The outcome or independent variable was musculoskeletal injury; (3) Temporality concerning fitness testing and injury had to be articulated with fitness testing occurring prior to injury; (4) A measure of physical fitness was included; (5) The association between at least one physical fitness measure (including self-report of fitness level) and injury was analyzed; and (6) The article was written in English.

3.2.3. Study Selection

Two reviewers (LL and JR) independently reviewed the title and abstract of the articles identified in the initial search to ascertain articles to be included for further assessment. Additional studies were included based on the search of article bibliographies. If there was no unanimous consensus on whether an article met inclusion criteria, a third author (DV) performed an assessment. Articles were excluded if temporality regarding the fitness testing in relation to the injury was either unclear or fitness testing occurred post-injury (Figure 3.1).

Figure 3.1 PRISMA Diagram



3.2.4. Assessment of Study Quality

Each of the selected studies were assessed for quality independently by the two reviewers (LL and DS) using the Newcastle-Ottawa quality assessment Scale (NOS) for cohort and case-control studies. This scale is designed for non-randomized studies and uses a star system to semi-quantitatively assess study quality by assigning one star for each item; participant selection, comparability of results, and quality of the outcome. Each category can be awarded up to three points and therefore the quality of studies could range from a low score of zero to a high score of nine. This scale was used to compare robustness of study methodologies to allow for a better interpretation of results and has been recommended by the Cochrane Collaboration (49).

3.2.5. Data Extraction and Synthesis

Information extracted from the relevant studies included in this review was entered into a Microsoft Word (2016, Windows) table for analysis. Data extracted included: author, study design, fitness measures, injury definition/ascertainment, and major findings. (Table 3.1) The dependent variable was work-related musculoskeletal injury (MSI) and the independent variables were scores from fitness testing. Relevant fitness measures included measured body fat percentage, flexibility, and estimated or measured maximal oxygen consumption. Information on injury occurrence including overall, overuse and/or acute MSI was extracted from medical records, workers compensation claims, or self-report. Findings were qualitatively synthesized to determine the best evidence of association between injury risk and physical fitness. Injury incidence was re-calculated for the 9 studies that included a measure of incidence to reflect a consistent unit of time and to facilitate an easier comparison. (Table 3.2). Because of heterogeneous statistical designs between studies, a quantitative synthesis was not performed.

Table 3.1 Article Summary

Author/NOS Score	Title	Objectives	Participants	Deign	Fitness measures	Injury	Methods/Results	Conclusions
Boyce 1992 **6***	Worker's compensation claims and physical fitness capacity of police officers	Investigate the relationship between physical fitness and worker's compensation claims. To further the understanding of the physical trait (physical fitness) as opposed to the 22ehavior (physical activity/exercise program participation) in connection with injury prevalence.	Police officers at a large metropolitan department in a major SE City in the US. Excluding recruits 514 – 436 male, 78 female Mean age 34.8	Retrospective cohort 1 year – 1988	Annual fitness test – BF%, sit and reach, sit-ups, 1RM bench press, Queens College Step test (<34 yrs) or YMCA bicycle ergometer evaluation (35 yrs+) Percentile cut-off scores Score rated 1-5 (low-high)		ANOVA WC or no WC and dollar amount if WC 92 (22%) males and 30 (38.5%) females collected WC Most officers that collected were younger Stat. sig more females collected Males who collected were more flexible, had greater ab endurance and 1RM but there were no differences in physical traits for females Fitness levels 2 and 4 were sig., diff in compensation amounts with level 4 males collecting the most and level 5 collecting Lowest. Similar pattern for females Only the bicycle score for males 35+ was significant	Male officers were who collected WC were more flexible, stronger and had greater ab endurance Those who collected WC were sig younger May be related to opportunity to take job-related risks Officers who fell into level 4 fitness category had greatest WC claims but also largest SD The least and most physically fit had lowest WC claims CV fitness was the only individual fitness measure that produced sig. differences in WC between fitness levels Overall the group of officers that collected WC had a greater %

								females, were younger, had lower rank, and tended to have higher physical fitness than those who did not. Level 4 fitness, older and greater CV fitness had sig. higher WC costs. Evidence to support the assumption that officers in level 5 fitness may have had a protective effect against injury (but few were in this category)
Butler 2013 **5***	Modifiable risk factors predict injuries in firefighters during training academies	Examine if the FMS is a successful predictor of injury in firefighter trainees. To examine if FMS baseline scores were associated with injury over the course of training. Examine whether standard measures of performance in firefighters had a sig. relationship with injury status	Firefighters enrolled in 4 successive training academies for the Orange County Fire Authority – each 16 weeks long Currently free from injury that would restrict participation 108 subjects	Prospective cohort	7 FMS subtests (21 points) Sit and reach Pushups (2 minutes 40 bpm, full extension, chin to block) max. 80 pushups Pull ups (standard? Chin over bar) 1.5 mile run time Tower Test – firefighter specific test	Any episode that caused the recruit to miss 3 consecutive days of training due to MSK pain – burns excl. Generic definition	Forward & backward log regression for injury prediction models Both physiologic and FMS variables collected at baseline were sig. predictors of injury. Sit and reach was the only physiologic variable that was predictive of injury (OR 1.24(1.06-1.42)) FMS deep squat (OR 1.21(1.01-1.42)) and push up (OR 1.30(1.07-1.53)) A cut point of ≤14 out of 21 was identified to dichotomize those at greater risk for	Musculoskeletal movement patterns, along with the sit and reach test are predictive of injury in firefighter recruits n training. Firefighters who scored ≤14 on FMS composite had a greater likelihood of injury Performance on the sit and reach, along with FMS deep squat and push up are related to injury risk (all of which have been documented as modifiable in previous research)

							developing and injury (OR 8.31(3.2-21.6))	Beneficial for recruits to meet a baseline level of functional fitness prior to entering training in order to minimize injury.
Cady 1979 **6***	Program for increasing health and physical fitness of fire fighters	To examine the effect of a health program in maintaining the health of Los Angeles fire fighters	1725 firefighters in Los Angeles between 1970 and 1979 998 older 727 younger	Prospective cohort Examining the effect of individual exercise programs and fitness counselling	Phys exams and exercise testing done at intervals averaging every 3 years Resting ECG, blood work Firefighters tested for physical work capacity (PWC), job-related strength, spine flexibility Physical activity was evaluated by interview Physiological measurements were done	Not clearly defined. WC claim	1)Comparisons of fitness measures for a sample of firefighters in similar age groups before and at least 9 years after the start of the program (617 before June 1, 1973, and during 805 examinations in 1982) 2)Comparisons of a subgroup of the same 188 fire fighters before and after the start of the departmental program (measurements made during the 1st exam and the 5th exam were analyzed) these 188 firefighters were selected because they had at least 5 examinations Relationship btw. Physical fitness and occupational injury and claim costs: 1)1652 healthy FF ranked on fitness scale (high, med, low) and # and costs of back injuries analyzed 2)320 healthy FF 40-49 yrs. Examined and	At baseline current problems with back (12%), knee (6%), and other MS areas (11%) were the most numerous complaints. In prospective study of 1652 FF 7% in low fitness experienced non-vehicular back injuries; 3% of those in the middle category and 1% in the high had back injuries – This indicated that protection of the back was associated with better than average fitness in all 5 measures The individuals with either greater flexibility of strength or work capacity were characterized by much lower back and total injury costs. This indicates protection from back and other injuries when the individual

							ranked according to 4 measures (flex., strength, BF%, PWC) upper 1/6 and lower 1/6 contrasted and analyzed for # and cost of injures	had better flex. Or strength or work capacity. Obesity did not demonstrate a particularly adverse influence on AC costs The 14-year program has been associated with a 16% increase in PWC, a slight increase in spinal flexibility, no clear increase in muscle strength, a decrease in disabling injuries, and a 25% decrease in WC costs per $100 payroll
Jahnke 2013 **7***	Obesity and incident injury among career firefighters in the central US	To prospectively evaluate obesity as a risk factor for incident injury among firefighters in a population-based cohort	9±1 month follow-up for 301 full-time firefighters uninjured at baseline Male only	Prospective cohort	BMI BF% bioelectric impedance Waist circumference' Height Physical activity – self-report of physical activity (SRPA) Torso strength – Flexibility	Self-report – injury incurred since baseline assessment – anything for which an accident report for the department was completed, reported to WC or received medical care (by a physician or medical professional) Number, type, location, duty, activity	No statistical differences in demographics between injured and uninjured First reported injury was use for anyone reporting multiple injuries Logistic models to examine relationship between body comp., demographics, and health 25ehavior at baseline and subsequent incidence of any injury and MS injury Risk adjusted models were controlled for age, smoking and physical	Sprains, strains & dislocations most common 57.1% Most injuries during training Incidence for any injury over 9±1 months = 15.3% No demographic, body comp, fitness or health 25ehavior measures were sig. predictors of any injury longitudinally Incidence of MS injury over 9±1 month = 6.9% only

						MS injury=sprain, strain, dislocation	activity fire department too	baseline body comp. was a sig. prospective predictor of MS injury with obese (BMI≥30kg m^{-2}) firefighters 5.2 (1.1-23.4) times more likely to experience MS injury than their normal weight (BMI_18.5-24.9) colleagues Those who were obese based on WC (>102 cm) were 2.8(1.2-6.4) times as likely to have MS at follow-up BMI and WC remained significant when corrected for department as a random factor
McGill 2015 **5***	Can fitness and movement quality prevent back injury in elite task force police officers? A 5-year longitudinal study.	To assess the links between components of fitness and movement ability of a cohort of police officers with subsequent injury over a substantial period of time.	53 Male members of elite ETF of a major city police department who stayed for 5 years Mean age 37.9 SD5	Prospective cohort	Perceived fitness – scale 1-10 Static muscular endurance – sit-up, front plank, side plank/bridges, Biering Sorensen extension Absolute (grip) and body-size normalized (pull-ups)strength Passive hip ROM	Any back injury not due to any specific acute incidents such as trips, slips, falls and other accidental mechanisms. Only new injuries	Independent t-tests on all independent variables to provide a rough idea where signal strength resided Backward Wald stepwise regression on grouped subjects and independent variables (subject info, fitness tests, hip ROM, movement competency tasks and FMS tests)	14/53 (26%) 5-year incidence of back injury Model that best predicted injury included = static sit up+Biering Sorenson+hip extension with knee flexed+pelvic rock+side plank 64% prediction accuracy A substantial amount of variance in back injury incidence was explained with torso

					FMS tests 1-7 13 additional movement tests chosen to reflect tasks often used by clinicians to evaluate injury risk or return to work status			muscle endurance, hip asymmetry, and the pelvic rock test but as a medical screen for individuals is weak (should be 90%) The model was better at predicting who would not sustain injury (95% correctly predicted) Injury prediction is complicated. The complexity of interaction between exposure, movement competency, training and fitness occludes the relationship between these variables. Nonetheless the ability to predict back injury is one of the highest reported over a 5-year follow-up period
Orr 2016 **8***	Leg power as an indicator of risk of injury or illness in police recruits	To investigate the relationship between leg power, as measured by a vertical jump, and rates of reported injuries and illness during police recruit training.	1021 police recruits in training in Australia 12 weeks January 2013 – June 2014 Session 2 was selected as the	Retrospective cohort	No Demographic data available Vertical jump height – rapid movement with arm swing at wall – maximal jump, 2 attempts	Physical damage to the neuromusculo-skeletal system of the body Determination made by medical staff	Independent sample t-tests – differences between injured and uninjured groups Spearman's Rho correlations used to determine differences between VJ heights and rates of injury	158/1021 (15%) injures over 12 weeks Sig. lower mean VJ heights for injured compared to those not injured p=0.003 Relative Risks – recruits with the lowest VJ heights were more than 3x as likely as those with

			intervention measure					highest VJ to suffer injury or illness similar trends for illness Correlations between VJ height and prevalence of illness and injury were low (r=-0.16 and -0.09 respectively) but significant (p<0.005) with VJ height accounting for 2.6% and 0.8% of the variance in illness and injury rates respectively.
Orr 2017 **7***	Grip strength and its relationship to police recruit task performance and injury risk: A retrospective cohort study	To evaluate the predictive validity of grip strength in police recruits for predicting police task performance and to identify relationships between grip strength and potential for injury during training.	169 police recruits participating in 12 weeks (session 2 – key assessments of occupational tasks) training in 2013	Retrospective Cohort	No Demographic data available Right and left grip strength using TTM original dynamometer, Tokyo, Japan Two recordings taken for each hand but if greater than 5% difference a 3rd measure was taken. Highest measure used. Minimum standard – 30kg	Physical damage to the neuro-muscular system of the body Determination of injury was made by treating medical staff unaware of the research	Spearman's correlation – used to establish relationships between ordinal outcome measured (injury=1/0) Pearson's correlation – assess relationship between grip strength and marksmanship scores Independent *ttest* conducted to identify differences in mean grip strength between injury and no injury groups Mean grip strength: RT 42.15kg ±8.29; LT 41.94kg±8.53	Only 5.3% did not meet the minimum standard and of these, 77% either failed an assessment or became injures 25.4% of Sj reported an injury (n=43) There was a significant difference between meant grip left in injured (n=43; 39.28±8.92) and uninjured 42.80±8.23 (p<0.01). No significant difference in RT grip strength Injury risk was negatively and weakly correlated

								with left hand grip strength, but not right hand grip strength Limitation: sample size- injury was relatively rare Research needs more detailed injury data and larger samples
Poplin 2013 **7***	The association of Aerobic fitness with injuries in the fire service	To establish and understand the relationship between fitness status and the risk of injury in a 5-year occupational cohort of career firefighters	Career firefighters in Tucson Arizona followed for 5 years Median follow-up 2.5 (at least 1 injury), 3.2 (at least 1 exercise injury), 2.8 (at least one sprain/strain) years Between 577-694 at the end of each calendar year from 2005-2009 799 underwent at least 1 physical exam 5% female	Retrospective Cohort	Anthropomorphic measures: height, weight, BF% VO_{2max} (ml/kg/min) – estimated using incremental treadmill protocol to targeted HR (Gerkin1997) and guidelines suggested by WFIIAFF (25 and 50th percentile cut off points: less fit <43, high fit >48)	Injuries that occurred on the job that were reported to OHS if they were deemed non-reportable but were internally documented because of the potential for the injury to progress to a point of requiring an insurance claim. Cardiac, heat illness, stress excluded	Cumulative incidence – Kaplan Meier Cox proportional hazards for time-to-event analysis Total 773 injuries: 357 people sustained at least one injury of any type, 174 sustained at least 1 exercise-related, 294 sustained at least 1 sprain/strain Overall, sprains/strains accounted for 67% of all injuries and 89% of exercise injuries 30% of all injuries resulted in lost time VO_{2max} HR adjusted for age and sex: All injures: 0.959 (0.946-0.972) – a 1 unit increase in VO_{2max} decreased the risk of injury 0.041 times	**Kaplan Meier –** Median time to injury increased with age (10 yr age group) No sig. gender differences but only 5% female Increases in BF associated with increased incidence rate most notably in those in highest tier (>36% BF) Sig. increases in incidence rate with decrease in VO_{2max} Those with lower VO_{2max} (ml/kg/min)were likely to sustain injury sooner than those who were more fit (median time 2.24 less fit, 4.07 most fit p<0.001)

							Exercise related: 0.960 (0.941-0.979) Sprains/strains: 0.952 (0.937-0.967) Effect modification of age assessed with stratified analysis	**Cox Regression** – Time to first injury as a function of fitness 1 MET is 3.5ml/kg/min thus these results suggest that improving one's aerobic capacity by 1 MET of task would reduce risk of injury by approximately 14% (3.5*4)*100 Age proved to be a sig. modifier of VO_{2max} ($p<0.001$) – The risk of injury among those with decreased VO_{2max} was higher in persons younger than 30 years of age than in those 30 yrs+ (Table 6) almost double
Poplin 2016 **7***	Fire fit: assessing comprehensive fitness and injury risk in the fire service	To present a more comprehensive measure of fitness for the fire service by integrating a range of fitness measures into a summary score that reflects the five ACSM's components A single-component of fitness may not represent an individual firefighters fitness for duty or their	799 firefighters 4.9% females	Retrospective Cohort	Annual fitness assessments for the years 2005-2009 7-measures: CV Gerkin submax treadmill Resting HR Handheld dynamometer – grip strength	Injury outcomes collected from standard department-level surveillance	ICC to assess variability calculated to assess variability within and between individuals' annual fitness measures - VO_{2max}, push-ups and sit-ups not consistent within and between sj - Flex, grip strength BF% more consistent over time	Hazard more pronounced for sprains and strains Age was shown to be a sig. modifier of the risk associated with comprehensive fitness Two findings are apparent: the risk of injury was greatest for those in the worst tier of comprehensive fitness regardless of age; younger individuals (<30)

		ability to perform all job-related tasks in a safe and efficient manner			Push-ups (metronomic pace 2 min) Sit ups (metronomic pace 3 min) Sit and reach – low back and hamstring flexibility BMI and WC BF% - bioelectric impedance Cut off values 25th and 50th percentiles Push-ups and pull-ups pass/fail Comprehensive fitness score – equally weighted		# injuries same as above article Time-to-event – Cox utilizing repeated measures – for individuals with a lower fitness status there was an increased injury hazard than those in the most fit category Adjusted for gender and age: All injuries: 1.82(1.06-3.11) $p<0.05$ Exercise injuries: 1.60(0.72-3.53) Sprains/strains: 2.90(1.48-5.66)	maintain a greater injury risk (especially sprains & strains) than older individuals While aerobic capacity is a metric most commonly used in the fire service to gauge fitness, a more comprehensive fitness measure may help describe a person's overall functionality as most fire response activities can require dynamic movements and physiologic demands
Studnek 2007 **6***	Factors associated with back problems among emergency medical technicians	To establish whether there is a relationship between the likelihood of reporting back problems and an individual and work-related characteristics of a national sample of EMT's	579 EMTs 104 cases – reported new back problems in 2004 475 controls – reported no back problems in 2003 and 2004	Case-control Randomized stratified sampling	Self-reported fitness level – 4-point Likert scale (excellent, good, fair, poor) age	Self-reported back problems in the last 12 months	A case-control analysis was performed on participants who reported no history of back problems in 2003&2004 (controls) Cases were subjects reporting new back problems in 2004 and compared to baseline data (aka fitness level from 2003 annual survey.) Logistic regression final model was derived by considering both stat. sig.	Low response rate (31.8%) N=864 with 579 meeting inclusion criteria Odds of back problems in relation to self-reported physical fitness (adjusted for certification level, job task (transport of patients), age, and job satisfaction

							and evidence for confounding Few reported fair or poor fitness so they were grouped together	Excellent OR=1 Good OR=3.95(1.72-9.06) Fair/Poor OR=3.63(1.36-9.67)
Wynn 2012 **8***	Cardiorespiratory fitness selection standard and occupational outcomes in trainee firefighters	To establish whether a reduction in, or an elimination of, a defined cardiorespiratory fitness standard for firefighter recruitment impacted on a number of occupational health-related outcomes.	Firefighter recruits commencing and exiting training between January1, 2004 and December 31, 2007 in Northern England -> 308 full-time with fitness standard of 42ml O_2/kg/min 198 recruits commencing and exiting training from 2004 to December 31, 2007 with no standard		Chester Step Test (CST) a validated sub-maximal estimate of maximal oxygen uptake Predictor variables – sex, age, application/non-application of a CV fitness standard, actual VO_2			For full –time recruits, a moderate positive correlation, with injury rates was found with the CF42 used/not used as a predictor variable (r_s=0.32, P<0.001 Increasing age was found to be significantly correlated with reduced incidence of the outcome variables “restrictions” and “injury”

Studies included 10 cohort and one matched case-control design with study follow-up periods ranging from 12 weeks to 9 years. Of the included studies that reported incidence of injury, the cumulative incidence rates per 100 workers per year ranged between 5.3 and 101.8 injuries per year (50–52). Injuries were ascertained in various ways including self-report, workers' compensation claims, and surveillance records. The definition of injury was often general; being any injury meeting workers' compensation requirements. Other studies defined an injury as any back injury, or a sprain, strain or dislocation. Sprains, strains, and back injury were the most commonly reported injures. Statistical methods varied between studies. Some studies compared fitness scores or WC costs between groups to determine if there were statistically significant differences while in other studies regression models were developed to determine the relationships between fitness and injury.

3.3.2. Study Quality

The included studies scored between five and nine points on the Newcastle-Ottawa Scale (NOS) (Table 3.1). Points are awarded regarding three components; selection, comparability, and outcome. The 10 cohort studies were examined for the representativeness of the cohort, selection of the unexposed cohort, ascertainment of exposure and demonstration that the outcome of interest was not there at the start of the study. Two studies had lower scores because self-reports were used as an assessment of outcome rather than data linkage or independent blind assessment (53,54). Three studies scored two points for comparability as multiple confounders were controlled for (19,51–56), whereas three studies scored zero points as no confounders were controlled for (57–60). The single case control study was evaluated regarding selection, comparability, and exposure. This study lost points for using self-reports for the ascertainment of exposure and case definition (61). Overall, studies were deemed moderate to high in methodological quality as no study received less than five points.

3.3.3 Factors Related to Musculoskeletal Injury

Only one study examined factors associated with injuries to emergency medical technicians and this was limited to self-reported back injuries suffered within the previous year. No specific fitness measures were made in this case-control analysis, but the findings indicate that the odds of back problems were almost four times greater in those who felt their fitness was good or fair/poor compared to those who reported having excellent fitness prior to their injury (61).

Four studies looked at police officers. In the two studies that observed Australian police recruits during training, specific fitness tests, including vertical jump height and hand grip strength, were examined as potential predictors of injury risk. Injury incidences during training were 60.8 and 101.8 per 100 trainees per year respectively (56,58). Leg power was assessed using vertical jump height and was significantly lower for recruits who became injured compared to those who did not. Vertical jump height accounted for 0.8% of the variance in injury risk between groups. Recruits with the lowest jump heights were on average more than three times more likely to suffer an injury than those with the highest vertical jump height (56). Mean left grip strength was significantly less ($p<0.01$) for injured (39.28kg±8.92) compared to uninjured (42.8±8.23) recruits but there was no significant difference in right grip strength between groups (58).

Compared to recruits, task force and standard duty police officers demonstrated a significantly lower incidence of injury at 5.2 and 22.0 per 100 workers per year respectively (32,54). Boyce *et al* (1992) compared annual fitness test scores between police officers who did and did not file workers' compensation injury claims. Overall, the group of officers that collected workers compensation were more likely female, were younger, and had a lower rank than those who had not filed a workers' compensation claim. Male officers who claimed workers compensation demonstrated increased flexibility, strength, had greater abdominal endurance, and were significantly younger. There were no significant differences in component fitness scores between females who filed a workers' compensation claim and those who did not.

Fitness level was determined through a composite score that included component test scores for body fat percentage, flexibility, sit-ups, one maximal bench press repetition, and estimated maximal oxygen consumption (ml/kg/min). A composite score of 1 was considered the lowest score and 5 was the highest score possible. Officers who scored a 4 of a possible of 5 had the greatest workers compensation costs. The least (score of 1) and most (score of 5) physically fit had the lowest workers' compensation costs. Of all fitness measures, cardiovascular fitness was the only individual measure that was associated with significant differences in workers compensation costs with decreased cardiovascular fitness being associated with increased health costs (32). This may indicate that police officers with lower cardiovascular fitness suffer less frequent but more serious injuries compared to their peers with greater cardiovascular fitness.

The relationship between back injury, movement quality, and fitness in police task force members was examined by McGill *et al.* (2015) using 7 of the tests that comprise the Functional Movement Screening (FMS). FMS includes a series of movements developed to assess the quality of fundamental movements, namely muscle strength and flexibility imbalances, which may be risk factors for injury which are overlooked by more traditional medical and fitness evaluations (62,63). An FMS score less than 15 out of a possible 21 has been found to be related to increased injury risk in athletes and military personnel during training (64,65). Thirteen additional movements, chosen to reflect tasks often used by clinicians, were included to evaluate injury risk and involved core muscle endurance tests, hip range of motion tests and other movement competence tasks. This study concluded that individual test parameters had low predictive value but could still be modeled to predict injury. Increases in back injury incidence appeared to be explained by lack of torso extensor muscle endurance, hip motion asymmetry, and hip felxibility (pelvic rock test). It was found that increased abdominal endurance was associated with lower back injury. The major conclusions of this study were that there may be an optimal, moderate level fitness for injury resilience and the model developed was better at predicting those who did *not* sustain back injury (54).

Four research articles focus on career firefighters. Only one of these studies ascertained injury from an injury surveillance system within the fire department. Two other studies used workers compensation reports as an indicator of injury and one study used self-reported injury. Firefighter trainees were participants in two studies; one in the United States (66) and the other in England (55).

During 16 weeks of firefighter training, 108 trainees from 4 successive classes completed fitness tests including the sit and reach, timed push-ups, pull-ups, 1.5-mile run, the Tower Test (a firefighter specific test), and 7 FMS subtests at the start of training (66). Any episode of musculoskeletal pain that required the recruit to miss 3 consecutive days was considered an injury. Both physiologic and FMS variables collected at baseline were significant predictors of injury during training. The sit and reach test for hamstring and back flexibility was independently predictive of injury (OR: 1.24 (95% CI: 1.06, 1.42)). FMS tests including the deep squat and push up were also predictive of injury (OR: 1.21 (95% CI: 1.01, 1.42)) and (OR: 1.30 (95% CI: 1.07, 1.53)) respectively. Participants with an FMS cut-off score ≤14 were at increased risk for injury although the confidence interval was not precise (OR: 8.31 (95% CI: 3.2, 21.6)).

Comparatively, firefighter trainees completed the Chester Step Test, a validated submaximal test for estimating maximal oxygen uptake in ml/kg/min (55). One group required a maximal oxygen consumption value (VO_{2max}) of at least 42 ml O_2/kg/min to be recruited and the other group did not. A moderate positive Pearson correlation (r_s=0.32, p<0.001) with injury rates was found, with those not passing the maximal VO_{2max} standard reporting an 8% (95% CI:

7.16%, 8.84%) increase in injuries reported during training. Advanced age was significantly correlated with a reduced incidence in injury and duty restrictions in this group.

Cardiovascular fitness and its association with injury risk was retrospectively examined in a group of career firefighters in Tucson, Arizona from 2005 to 2009 (52). Maximal aerobic capacity was estimated using an incremental treadmill protocol. Statistically significant increases in incidence rate for all injuries, injuries sustained during exercise, and sprains and strains were observed with a decline in VO_{2max}. Firefighters with lower VO_{2max} levels were more likely to sustain an injury sooner than those who were more fit (median time to injury of 2.2 years compared to 4.1 years). The authors suggest that a VO_{2max} increase of 3.5 ml/kg/minute would reduce the risk of injury by 14%. Age was a significant modifier of VO_{2max} with the risk of injury among those with decreased VO_{2max} being higher in firefighters younger than 30 than those 30 years of age or older.

The longest prospective study observed firefighters over 9 years with physiological testing done approximately every 3 years (67). Injury was not clearly defined in this study but appeared to focus on back injuries ascertained through interviews and workers compensation files. Fitness measures included a physical work capacity test specific to firefighting, muscular strength, flexibility, and cardiovascular heath but specific field tests were not identified. The results indicated a significant association between increased fitness scores and decreased back injury complaints. Overall, this study found that over 14 years, the implementation of a health promotion and physical fitness program decreased workers compensation costs and back injury complaints.

Poplin *et al.* compared composite fitness scores between injured and uninjured firefighters between 2005 and 2009 (51). Seven measures of fitness made up the physical assessment and included a submaximal treadmill protocol to test relative aerobic capacity (VO_{2max}), resting heart rate, grip strength, push-ups, sit-ups, low back and hamstring flexibility, body mass index (BMI), and waist circumference. Three levels for each fitness component were established and the 20th and 50th percentiles were used to identify the less fit and high fit groups. The comprehensive fitness score equally weighted all components measured. Results indicated that firefighters with lower fitness had an increased injury hazard rate compared to those who were most fit. This difference was most pronounced when sprains and strains were considered rather than all injuries. The least fit firefighters were at almost 3 times the risk for sprains and strains compared to their most fit colleagues (hazard ratio (HR): 2.90 (95% CI: 1.48, 5.66)). The trend was in the same direction when exercise-related injuries were considered, but the measures of effect were not significant (HR: 1.60 (95% CI: 0.72, 3.53)).

The association between obesity and injury incidence was investigated in another study involving career firefighters where workers compensation files were reviewed (53). Dislocations, sprains, and strains were classified as MSIs. Body composition was measured using bioelectric impedance, physical activity was assessed using the self-report of physical activity (SRPA) questionnaire, and torso strength and flexibility were also measured. No demographic, fitness, or health behaviour measures were significant predictors of injury risk. However, baseline body composition was a significant positive predictor of MSI. Obese (BMI≥30 kg/m^2) firefighters were 5.2 times more likely (95% CI: 1.1, 23.4) to sustain an injury compared to their non-obese (BMI: 18.5 to 24.9 kg/m^2) colleagues. Obesity as measured by waist circumference (>102.0 cm) was also associated with an increase in injury risk (OR: 2.8, 95% CI: 1.2, 6.4).

3.4. Discussion

The purpose of this systematic review was to provide an overview of the current evidence for the relationship between physical fitness test scores and risk of occupational injury in emergency responders. A comprehensive search yielded 11 relevant studies with one-year injury incidence for firefighters ranging from 11.2 to 30.4 injuries per 100 firefighters. Firefighter trainees demonstrated one-year injury incidences of 97.7 per 100 full-time trainees and 15.8 per

100 part-time trainees. Police trainees demonstrated incidences between 60.8 to 101.8 injuries per 100 trainees per year whereas career officers and elite officers demonstrated rates of 22.0 and 5.3 injuries per 100 police officers per year. The studies included were assessed for quality using the Newcastle-Ottawa Scale and received between 5 and 9 points. Overall, studies were deemed moderate to high in methodological quality as no study received less than 5 points. Scores could have improved in several studies if confounders were controlled or adjusted or if the assessment of the outcome was done by record linkage or independent, blind assessment rather than by self-report. Unfortunately, the limited number of studies available was heterogeneous regarding observation period, number of participants and, measures of fitness making comparison between them difficult. Injury case definitions across studies were also dissimilar with several studies being very unclear regarding what constituted an injury.

Despite the limitations listed above, synthesis of the findings provided some evidence for the relationship between physical fitness test scores and injury risk. Despite the use of different measures of aerobic fitness, a consistent trend between lower levels of aerobic fitness and an increase in injury risk and cost was found in 3 separate studies (32,52,55). A combination of physical fitness components may be related to the risk of occupational injury and some evidence indicates a relationship between composite fitness scores and injury burden. This limited evidence suggests that a high level of fitness may decrease injury costs (a possible proxy for severity) whereas a low level of fitness puts emergency responders at increased risk of more serious MSI. This needs to be investigated further. The relationship between age and injury risk can be conflicting and may be cofounded by ranks and occupational tasks. Younger emergency responders may be at increased risk for injury, but further investigation is required to ascertain whether it is indeed age that is related to injury or whether younger workers participate in riskier job tasks. For example, patrol officers who respond to calls for service are generally newer, younger, and are more likely to be in dynamic and hostile situations than those who have been promoted into more investigative positions. Finally, there is conflicting evidence regarding the relationship between body composition and injury risk in emergency responders. One study found no association whereas another indicated that obesity may increase the risk of injury.

The weak and sometimes conflicting associations found in the studies reviewed here could be due to several factors. First, the observation periods are vastly different between studies and it is possible that the shorter observation periods may not in some cases be long enough for an injury to occur. Trainees and incumbents have different tasks, task volumes, and task intensities. Trainees may often perform critical tasks repeatedly in a short training period in order to get their skills to the level required to partake in full duty. They may incur a minor MSI during training and not report it due to their desire to complete training and this may increase the potential for a more serious injury to occur once they are in the field. The increased injury incidence in incumbents may reflect overuse injuries whereas training injuries may be more acute. Levels of fitness within the group may have little variance therefore making it more difficult to observe strong associations. Regarding workers' compensation, the number of claims and cost of injury cannot be compared directly as one indicates the incidence and the other the burden of injury.

Finally, 4 studies did not indicate the sex of the population. Within the fire service, the population is approximately 5% female (51–53). Thus, females in three studies of firefighters were not analyzed due to either privacy or sample size concerns. Females account for approximately 20% of police officers and likely a greater proportion of emergency medical services personnel but this information was missing in the only EMT study and the 2 studies involving police recruits. This is a limitation of the existing research since males and females are physiologically different and physical fitness performance may not be comparable. In addition, males and females may have different injury profiles due to these differences in physiology.

3.5. Conclusion

Literature examining the relationship between physical fitness test scores and the occurrence of work-related MSI in emergency responders is scarce. Only 11 studies were identified for this review, and police and emergency medical personnel lack representation. Subsequently, evidence of relationships between many aspects of physical fitness and occupational injury is limited. There is evidence that increased aerobic (cardiovascular) fitness may have a protective effect against MSI but more research is needed. Future research should focus on individual components of fitness (flexibility, muscular strength, muscular endurance balance and agility) in isolation and as composite scores so that the relationships observed can be used to devise specialized fitness-training programs to reduce injury. It may be that there is an optimal level of fitness conducive to injury prevention. In addition, more effort should also be put into testing the interaction of sex and fitness regarding predicting injury.

Chapter 4: A description of musculoskeletal injuries in a Canadian police service

This chapter has been published as:

Liana L, Voaklander D, Gross DP, Guptill CA, Senthilselvan A. A description of musculoskeletal injuries in a Canadian police service: Int J Occup Med Environ Health. 2020;33(1):1 – 8. Available from: https://doi.org/10.13075/ ijomeh.1896.01454.

Miss Lentz and Dr. Voaklander conceived and designed the concept of the research study. Miss Lentz analyzed the data and drafted the manuscript which was reviewed by all other authors who offered revision suggestions. All authors reviewed the manuscript and gave final approval for the version to be submitted for publication. Miss Lentz, Dr. Senthilselvan, and Dr. Voaklander contributed to methodology. The original draft was written by Ms. Lentz. All authors listed in the bibliographic information contributed to reviewing and editing the article.

4.1. Introduction

Police officers perform tasks that are vast and varied, ranging from reading to children in an elementary school to chasing down a suspect wanted for a violent crime. Their responsibilities include preventing crime, apprehending those to be taken into custody, and fostering a cooperative relationship with the community. With these responsibilities comes the opportunity to interact with a large number of different people, whether invited or not, which can lead to hostile or dynamic situations that put them at increased risk for injury compared to those in other occupations (15). This presents a public health problem affecting both civilians and police officers. The individual suffering an injury may experience increased job stress, decreased productivity, limited physical ability, or the development of chronic or comorbid injury. Members of the community are affected by decreased service, increased response time to emergencies, and increased cost of maintaining services.

There is very little research regarding the epidemiology of police officer injury. Research involving first responders indicates this occupational group has 3 times greater risk of being injured at work than all other occupations (2). Additionally, it has been reported that firefighters have an injury rate 7 times that of the United States national average (44) and police officers have a 10% greater occurrence of injuries compared to firefighters (15). Much research has been done in regard to police officer occupational health and safety in regard to the impact of shift work (4,5)fatigue (6), catastrophic or fatal injury (7), violence (16) and use of force technologies (e.g. baton, oleoresin capsaicin spray, conductive energy device) (9-12). Even though the risk of musculoskeletal injury (MSI) for police officers is high (RR: 11.65; 95% CI:11.07-12.25) (2), research regarding MSI is lacking (8-13). Because MSI such as sprains, strains, dislocations, and fractures have been somewhat overlooked in the literature, the frequency of police officer injury may be underestimated.

The objectives of this study are to analyse injury data from a municipal police service in Western Canada in order to: 1) quantify injury prevalence and 2) identify the most common MSI experienced by police officers.

4.2. Materials and Methods

This was a cross sectional study of active police officers in a municipal police service in Western Canada. The mean number of police officers in this agency from 2013 to 2016 was 1,674 per year (312 female, 1,362 male)(68). Medical data were recorded by the Police Service using specialized injury report software between January 1, 2013 and June 2, 2016. Data were extracted from the police service medical database by the data manager and a subset of this data relating to MSI was analysed. An employee of the police service removed names and changed identification numbers prior to providing it to the researchers so that no individual could be identified. Data were obtained with permission from the Police Service and according to the Freedom of Information and Protection of Privacy Act. Ethical approval for this study was obtained from the University of Alberta Health Research Ethics Board.

The dataset was comprised of any reported injury that affected the police officer's ability to work at full capacity, that occurred between January 1, 2013 and June 2, 2016 and included the date of injury, date of birth, body part injured, diagnosis, work area, and sex. MSIs were identified through diagnostic categories compiled by the Police Service (dislocation, fracture, knee meniscus tear, non-specific pain, and sprain/strain). Body areas injured were classified as; upper extremities, lower extremities, torso or, head/neck. Body parts injured were classified as; ankle, arm, back, elbow, feet and toes, groin, hands and fingers, hip, knee, leg, multiple body parts, neck, shoulder, spine, and wrist. Any duplicate cases were identified based on the identification number, injury date, and body part injured and were removed prior to analysis. Only the first recorded injury for each subject was included in the analysis.

A descriptive analysis was conducted that included frequencies and proportions of reported injuries. Injuries were classified according to diagnosis, body region, and body part. Comparisons were made between sex, age, work area, and length of service. The prevalence rate was calculated by dividing the number of police officers who reported a new MSI during the observation period by the number of active police officers in the sample. Cumulative incidence was calculated over the 41-month observation period. Proportions between groups were statistically compared using the Chi-squared statistic and odds ratios with 95% confidence intervals. Continuous variables were compared using a t-test to obtain the significant differences between the means. The data analysis was conducted using SAS software, Version 9.4 (SAS Institute Inc, Cary, North Carolina).

4.3. Results

Between January 01, 2013 and June 02, 2016 there was a yearly average of 1,674 active police officers for whom demographic and injury data were available for 1,325 individuals. The sample consisted of 1,062 males and 263 females with mean ages of 34.4 (SD=6.1) and 34.3 (SD=6.5) years respectively. Over 41 months, the cumulative incidence was 106 injuries per 1,000 personnel, per year. Females and males experienced similar risk of being injured (OR 1.05 (95% CI: 0.79-1.40)). The female police officers who were injured were not significantly different in age than those who were not injured (p= 0.15) but injured males were significantly younger than those who were not injured (p=0.01). However, for both sexes, injured officers had significantly less years of policing experience than those who were not injured. (Table 4.1)

Table 4.1 Distribution of Injury by Gender and Years of Service

	Males (n=1062)		**Females (n=263)**	
	Injured	Not Injured	Injured	Not Injured
Number	388	674	93	170
Mean Age (SD)	33.7* (6.3)	34.7 (6.6)	33.7 (6.4)	34.8 (5.9)
Mean Years of Service (SD)	8.0 (5.0)	10.1 (5.9)	8.7 (5.5)	10.7 (5.2)

n=number of participants, SD=Standard Deviation, *p=0.01

Most injuries were diagnosed as sprains/strains (89.2%) and fractures (8.3%). (Table 4.2) The upper extremities were the most frequently injured body area accounting for 37.2% of injuries whereas the lower extremities accounted for 35.6% of reported injures. The torso was injured 20.1% of the time and the least injured body area was the head/neck at 6.2%. (Table 4.3) More specifically, the back and shoulder were the most frequently injured body parts accounting for 19.2% and 13.5% of all injuries respectively, followed by the hands and fingers (12.1%), ankle (11.3%) and knee (11.3%). (Table 4.4)

Table 4.2 Distribution of Body Part Injured Stratified by Sex

Body Part	Males (n=363) n (%)	Females (n=89) n (%)	Total (n=452) n (%)
Abdomen	0	1 (1.1)	1 (0.2)
Ankle	42 (11.6)	9 (10.2)	51 (11.4)
Arm	13 (3.6)	1 (1.1)	14 (3.1)
Back/Spine	67 (18.6)	21 (23.9)	88 (19.6)
Elbow	9 (2.5)	2 (2.3)	11 (2.4)
Feet/Toes	9 (2.5)	2 (2.3)	11 (2.4)
Groin	9 (2.5)	0	9 (0.2)
Hands/Fingers	43 (11.9)	12 (13.6)	55 (12.2)
Head/Face	3 (0.8)	1 (1.1)	4 (0.9)
Hip	4 (1.1)	5 (5.7)	9 (0.2)
Knee	44 (12.2)	7 (8.0)	51 (11.4)
Leg	26 (7.2)	4 (4.5)	30 (6.7)
Multiple Body Parts	1 (0.3)	3 (3.4)	4 (0.9)
Neck	23 (6.4)	1 (1.1)	24 (5.3)
Ribs	3 (0.8)	0	3 (0.7)
Shoulder	49 (13.6)	12 (13.6)	61 (13.6)
Wrist	19 (5.3)	8 (9.1)	27 (6.0)

Table 4.3 Distribution of Diagnosis Stratified by Sex

Diagnosis	Males (n=388) n (%)	Females (n=93) n (%)	Total (n=481) n (%)
Dislocation	4 (1.0)	0 (0.00)	4 (0.8)
Fracture	36 (9.3)	4 (4.3)	40 (8.3)
Knee Meniscus Tear	1 (0.3)	0 (0.0)	1 (0.2)
Non-specific Pain	3 (0.8)	2 (2.2)	5 (1.0)
Sprain/Strain	344 (88.7)	87 (93.5)	431 (89.2)

Table 4.4 Distribution of Injured Body Region Stratified by Sex

Body Region	Males (n=363) n (%)	Females (n=89) n (%)	Total (n=452) n (%)
Upper Extremities	133 (36.6)	35 (39.3)	168 (37.2)
Lower Extremities	134 (36.9)	27 (30.3)	161 (35.6)
Torso	69 (19.0)	22 (24.7)	91 (20.1)
Head/Neck	26 (7.2)	2 (2.3)	28 (6.2)
Multiple Body Regions	1 (0.3)	3 (3.4)	4 (0.9)

Data regarding work area were limited as it was recorded for 293 participants. Work areas were classified according to work tasks (recruit training, uniformed, administrative, investigative, support, specialized and plain clothed). Most of this subsample were uniformed, patrol/beat officers (68.3%) in that they wore a full uniform and were in contact with the public frequently while responding to calls for service (Table 4.5). The prevalence of injury by work area ranged from 25% to 48% with administrative and support staff demonstrating the greatest proportion of injuries. Overall, injury distribution was not significantly different between work areas (p=0.62) however, there was a significantly different distribution of males and females across the work areas (p=0.02). Females figured more prominently in administrative and support (uniformed but not in patrol) positions than males.

Table 4.5 Distribution of Injury Stratified by Sex and Work Area

Work Area	Males (n=238)		Females (n=55)	
	Injured (n=79) n (%)	**Not Injured** (n=159) n (%)	**Injured** (n=24) n (%)	**Not Injured** (n=31) n (%)
Recruit	2 (2.5)	6 (3.8)	2 (8.3)	0
Uniform	51 (64.6)	107 (67.3)	10 (41.7)	19 (61.3)
Administrative	5 (6.3)	6 (3.8)	4 (16.7)	4 (12.9)
Investigative	5 (6.3)	8 (5.0)	0	2 (6.5)
Support	8 (10.1)	9 (5.7)	5 (20.8)	5 (16.1)
Specialized	3 (3.8)	8 (5.0)	0	1 (3.2)
Plain Clothes	5 (6.3)	15 (9.4)	3 (12.5)	0

4.4 Discussion

During the 41 months investigated, 481 injuries were reported in this group of police officers indicating an injury incidence rate of 106 per 1,000-person years. This is greater than the findings of Gray et al. who stated that police officers in Australia had an incidence of musculoskeletal injury of 46 per 1,000 workers (2) and to the United States Bureau of Labor Statistics who reported that in 2014, among police officers, the rate of nonfatal occupational injuries and illnesses requiring time off work was 48.6 cases per 1000 full-time workers(5). Relative to other research the prevalence of injury in this study is similar to results previously recorded (85-2,500 injuries per 1,000 workers, per year) (5,8,16-25). Differences in injury incidence in the existing literature could be due to several methodological reasons including differential definitions of injury, the nature of the study, and the source of the data used in the analysis. Varied definitions of injury may explain differences in injury incidence between studies. A broad definition of injury would likely lead to increased injury estimates; however, this does not seem to be the case here. It is also possible that longer observation periods allowed for more injuries, such as repetitive strain injuries, to manifest.

Sprains were the most dominant injury type accounting for over 89.2% of all injuries. The back and shoulder were injured most frequently. The results of this study indicate that MSIs, especially sprains, are commonly suffered by police officers which concurs with previous reports. Sprains and strains are commonly prevalent in police officers accounting for between 17% and 61% of musculoskeletal injuries(14,16,23,26). In the current study, the proportion of strains and sprains was higher at 88%, outside of the range reported in the literature.

There is some inconsistency in the reported research regarding the most commonly injured area of the body. In general, it appears that police officers injure upper extremities more frequently than the lower extremities (31,33). The current study is consistent with findings that the back (34,35), shoulder (20), and leg (or lower extremity)(14,21,37) are most frequently injured; however, this study found a lower proportion of injuries to the hand, fingers and wrists

(11.7%) compared to other police based research where the hand, wrists and fingers were injured more frequently (17-21%)(14,31). Variations in the use of gloves and the availability of alternative use of force options (oleoresin capsicum spray, baton, or conducted energy device) may be protective and could account for the differences between studies.

In studies that compare sex, female officers were more likely to file workers' compensation claims(2) or receive compensation (19) but in general, there was little difference between genders in injury rates between males and females (21,31) as was reflected in the current study. The increase in workers' compensation claims and receipt of compensation may be indicative of increased injury severity in female police officers. This information was not available for this study. Further research is required.

The difference in mean age between injured and uninjured males was statistically significant. Though the ages of injured and uninjured females are similar to that of males, the difference in age for injured and uninjured females is not statistically significant. This is mainly due to the smaller in the sample size The literature indicates that police officers of lower rank (21) or age (17,31) are at increased risk for injury and that police officers less than 40 years old are injured most often (2,17,31). The relationship between age and injury risk is complex and may be confounded by rank and occupational task. Younger police officers may be at increased risk for injury, but further investigation is required to ascertain whether it is age that is related to injury or whether younger workers participate in riskier job tasks. For example, patrol officers who respond to calls for service are generally less experienced, younger, and are more likely to be in dynamic and hostile situations than those who have been promoted into more investigative or administrative positions.

Little research has been done regarding area of work and injury and the non-significant relationship between work area and injury found in this study should be interpreted with caution. Accepting the non-significant relationship would require the assumption that the data was missing completely at random. Data regarding the physical task the officer was doing when they became injured was missing for most subjects so was not included in the analysis. However, the information that does exist shows a trend that suspect apprehension and physical fitness activities were most frequently associated with injury. Controlling and apprehending suspects (16,23,26), over exertion (31) and, training activities have been cited as the most common tasks being performed when a police officer becomes injured. Officer safety skills, tactics, tools, and training are associated with injury occurrence. As an example, the use of a conducted energy device has been shown to decrease the likelihood that an officer would have to have direct contact with or discharge their firearm on an assaultive or combative person, thereby decreasing injuries to both the officer and the people they deal with (10-32). It makes sense then that an area of work which involves increased opportunity to apprehend suspects, may also correlate with an increased risk of injury.

This study has several limitations. The data used was gathered for administrative purposes and were not intended for research purposes and the veracity of the data is not known. There are some missing data, but it is not known if this information is missing at random. The injuries recorded are only those that were reported to workplace management and are likely of a more serious nature and our data may exclude minor injuries. Existing research indicates that occupational injuries are underreported in many industries (32). For example, a Canadian survey found that 40% (95% CI; 32-48%) of workers who suffered a work-related injury had not filed a worker's compensation claim (69).

4.5 Conclusions

The findings from this study indicate that police officers suffer MSI frequently and the greatest proportions of injuries are sprains and strains. Police officers most commonly injure their lower extremity, back, and/or shoulder. Injury prevention efforts should focus on these injuries. Future research should investigate individual and organizational risk factors for injuries in order to guide prevention efforts.

Chapter 5: The association between fitness test scores and musculoskeletal injury in Police officers

This chapter published as Lentz L, Randall JR, Guptill CA, Gross DP, Senthilselvan A, Voaklander D. The association between fitness test scores and musculoskeletal injury in Police officers. Int. J. Environ. Res. Public Health 2019, 16(23), 4667; https://doi.org/10.3390/ijerph16234667 - 23 Nov 2019.

Miss Lentz and Dr. Voaklander conceived and designed the concept of the research study. Miss Lentz analyzed the data and drafted the manuscript which was reviewed by all the other authors who offered revision suggestions. All authors reviewed the manuscript and gave final approval for the version to be submitted for publication. Miss Lentz, Dr. Senthilselvan, Dr. Randall and Dr. Voaklander contributed to methodology. The original drafts were written by Ms. Lentz. All authors listed in the bibliographic information contributed to reviewing and editing the article.

5.1 Introduction

Police officers perform a wide range of tasks while upholding their duty to protect the public and prevent crime. Even though much of a police officer's daily duties are sedentary, this career is hazardous and physically demanding (70). At any given time, there is potential that a police officer will be involved in a critical incident fighting for their life or protecting the life of another. In order to perform occupational tasks effectively and without injury, officers require adequate physical abilities and readiness.

Physical fitness describes a concept that is different from, and a component of, occupational physical ability or physical readiness. It has been defined in many ways. A general definition relates to the ability to carry out daily tasks without fatigue, leaving energy for leisure pursuits and to meet the physical stresses required in an emergent situation (71). Physical fitness is a set of attributes that are related to health and performance which can be measured with specific tests and can be broken down into the components of cardiorespiratory endurance, muscular endurance, muscular strength, body composition, and flexibility (72). Police officers are expected to have an above average level of physical fitness or physical aptitude to ensure that they can fulfill their duty to protect the community when involved in a critical incident. If officers are unable to perform their duties or are away from work because if injury or illness, the community is affected by decreased service, increased response time to emergencies, and increased cost of maintaining police services.

The occurrence of injuries has been an impetus for initiating employee fitness and wellness programs in a variety of organizations and evidence suggests that such programs may decrease injuries, absenteeism, and the cost of group healthcare benefits (73). Police officers who participate in fitness activities appear less likely to have an injury (37,45). Physical activity has also been found to protect against the negative effects of psychological stress (74), improve sleep (75) and may also lend to decreases in depression (76). Being responsible for public safety, police officers have a psychologically and physiologically demanding job and must have good mental and physical health in order to do their duty.

Occupational injury to police officers is an important public health problem not only because the incidence of musculoskeletal injuries (MSI) to police officers is higher than in most other occupations but also because having police officers absent from work affects the safety of the community. On average, in the U.S. and Australia, police have been found to have an injury rate three times greater than that for all other workers (1,2). In one municipality, police injury accounted for 48% of all emergency responder injuries compared to fire and emergency medical services who reported 36% and 18% of the total injuries respectively (15).

Research examining the relationship between physical fitness test scores and the occurrence of work-related MSI in police officers is very inadequate. In a recent systematic review, only 4 studies examining the relationship between fitness and injury in police officers were identified (3). Therefore, evidence of relationships between many aspects of physical fitness and occupational injury is limited.

The aim of this study was to investigate the relationship between scores on several fitness tests and musculoskeletal injury in a group of municipal police officers. The main hypothesis was that the mean scores on fitness tests would differ between injured and uninjured police officers. We investigated the risk of injury and fitness test performance to identify whether different components of fitness have differing relationships to injury.

5.2 Materials and Methods

Data

This was a retrospective study of active police officers in a municipal police service in Western Canada. The study received ethical approval from the University of Alberta Ethics Review Board. The yearly mean number of officers in this service during the study period was 1674 (77). A secondary data analysis was completed to examine the relationship between physical fitness and injury in active police officers. Fitness data included fitness test scores from annual fitness testing that were recorded at the time of testing in Excel by fitness unit employees. Fitness unit employees were employed by the police service and were either certified through the Canadian Society of Exercise Physiologists or the National Strength and Conditioning Association. Any MSI that affected a police officer's ability to work in full capacity, including those injuries that were not work-related, were self-reported to the police service. Injury data was recorded by the police service using specialized injury report software. Data were extracted from these databases by the data manager. To maintain anonymity, an employee of the police service removed names and changed identification numbers in the data sets prior to providing the data to the researchers. The data were obtained with permission from the police service and according to Alberta's Freedom of Information and Protection of Privacy Act. This study was approved by the University of Alberta's Health Research Ethics Board.

Subjects

The subjects included all active police officers in the police service who completed annual fitness testing between January 1, 2013 and June 2, 2016. Since fitness testing is mandatory until the age of 45, only those police officers that were 45 years of age and under during the observation period were included. In total, data on 1,006 subjects were available for the study.

The annual fitness test consisted of several field tests and included measures of body mass, body fat percentage (bioelectric impedance), hand grip strength (kg), vertical jump height (inches), leg power (kg), number of pull-ups, kilograms pulled, number of times push ups, plank time (min), and maximal oxygen consumption in milliliters per kilogram per minute (VO_{2max} ml/kg/min) (Appendix II). VO_{2max} was measured in ml/kg/min in1 of 2 different ways during testing, either indirectly measured using the 20-meter shuttle run test or directly measured using a cycle or treadmill ergometer. Less than 10% of subjects had VO_{2max} directly measured. Research indicates that the results of either measure are comparable. The mean scores between the shuttle run and direct measure did not vary significantly so the values were combined in the analysis (see Appendix II for more details of the fitness test).

For this study, MSI were identified in the medical data as injuries diagnosed as dislocation, fracture, knee ligament injury, knee meniscus tear, non-specific pain, or sprain/strain. Any duplicate data were identified based on the participant number, injury date, and body part injured and were removed prior to analysis. Only the first recorded injury was included in the analysis.

Statistical analysis

A descriptive analysis included means and standard deviations for continuous variables (fitness scores) and proportions and frequencies for discrete variables (sex, injury status, injury diagnosis, injury site). Significance of the differences in means were examined using a student's t-test. Odds ratios (OR) and 95% confidence intervals (CI) were used to compare risks between groups. A p-value of 0.05 or less was considered significant

A matched case control analysis was conducted to determine the relationship between fitness test scores and musculoskeletal injury (MSI). To adjust for possible temporal variation in training protocols or work activity, each case was matched on the date of fitness test, with 2 controls. Multivariate logistic regression was used to determine the effects of fitness scores on injury. Initially, univariate OR and 95% CI were estimated for each of the fitness measures. For the multivariate analysis, purposeful selection method was used for the model building (78). Effect modification was explored between the variables in the main effects model and any significant interaction terms were included in the final model. A sample size available was adequate to determine a odds ratio of approximately 1.20 or greater for the relationship between fitness test scores and musculoskeletal injury with a level of significance 0.05 and 80% statistical power. All statistical analyses were performed on SAS version 9.4 (SAS Institute Inc, Cary, North Carolina).

5.3 Results

Initially there were 1,357 subjects and 481 injuries. After matching, 1,006 subjects including 336 injured subjects remained for analysis. Subjects had a mean age of 39.7 years (SD=5.8) where the greatest proportion of the police officers were over 40 years of age (Figure 1). Females accounted for 14.5% of the subjects and had a mean age of 38.4 (SD=6.3) years whereas males had a mean age of 40.0 (SD=5.7) years. Years of service was similar between sexes where females had an average of 14.4 (SD= 9.0) and males had an average of 14.1 (SD= 6.6) years of service. During the study period, there were 336 new MSI reported and 89.3% of these injuries were diagnosed as sprains and strains. Females accounted for 17.9% of the injured subjects.

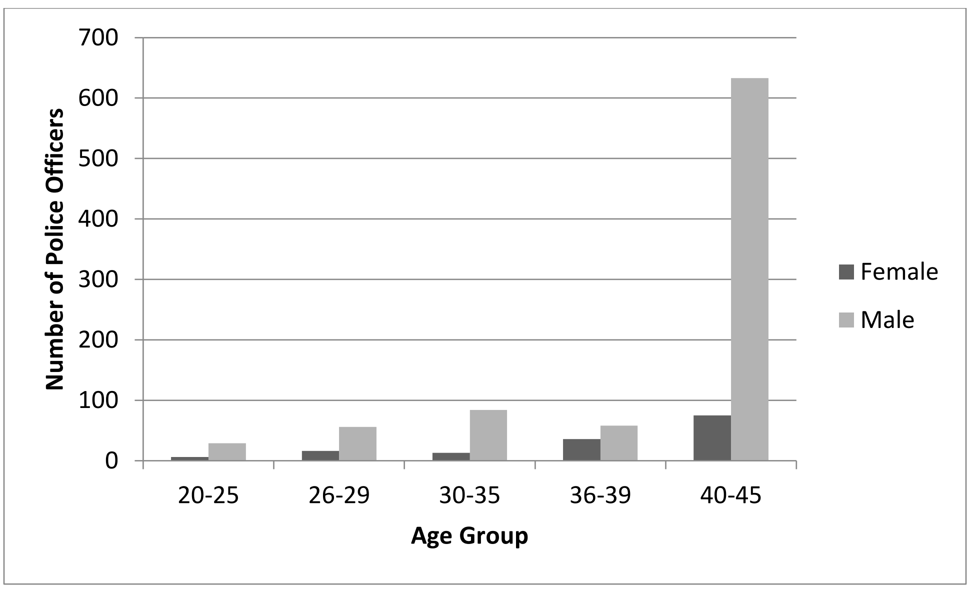


Figure 5.2 Distribution by age group and sex

The mean fitness test scores for all police officers are summarized in Table 5.1. Not all the subjects did all the fitness tests so sample sizes (n) are shown to describe the missing data. There were significant differences in fitness test scores between injured and uninjured subjects in all measures except body fat percentage, body mass, heart rate, left grip strength, and combined grip strength. Injured subjects scored higher on fitness tests including right hand grip strength, vertical jump, leg power, pull ups, kilograms pulled, pushups, speed, maximal oxygen consumption (VO_{2max}), and plank time.

Table 5.1 Distribution of fitness test scores by uninjured and injured

	Uninjured					Injured					
Test	**n**	**Mean**	**SD**	**Minimum**	**Maximum**	**n**	**Mean**	**SD**	**Minimum**	**Maximum**	**p-value**
Body Mass (kg)	661	87.20	12.05	60.53	128.40	332	86.34	13.93	52.72	165.30	0.34
Body Fat (%)	670	20.50	6.17	10.30	44.70	332	20.24	6.95	4.40	43.00	0.56
Heart Rate (bpm)	667	74.81	10.57	48.00	95.00	323	74.88	13.25	47.00	118.00	0.94
Grip Strength Right (kg)	670	48.12	10.25	32.00	78.00	336	51.75	12.31	18.00	86.00	0.0001
Grip Strength Left (kg)	670	50.85	10.86	28.00	75.00	335	49.56	12.19	12.00	84.00	0.10
Grip Strength (kg)	670	98.97	20.54	60.00	153.00	335	101.39	24.00	30.00	169.00	0.12
Vertical Jump (inches)	667	108.92	5.72	93.50	117.00	323	110.8	6.96	90.50	128.00	<.0001
Leg Power (Watts)	667	4820.98	847.89	2247.62	6930.40	319	5167.34	1490.50	318.98	24407.39	<.0001
Pull Ups (n)	641	4.45	5.69	0.00	15.00	316	6.94	5.81	0.00	24.00	0.0001
Amount Pulled (kg)	641	384.41	490.41	0.00	1295.19	313	593.07	487.87	0.00	1915.43	0.0001
Push Ups (n)	669	28.7	11.24	10.00	54.00	324	32.49	10.75	0.00	67.00	0.0001
Speed (km/hr)	471	11.79	1.14	10.00	13.50	300	11.98	1.01	8.25	14.50	0.02
$VO_{2\ Max}$ (ml/lg/min)	508	42.24	5.86	32.59	53.60	316	44.02	6.70	20.58	59.60	0.0001
Plank Time (minutes)	670	2.56	1.02	0.77	5.00	328	2.69	0.91	0.13	5.73	0.04

The univariate analysis indicated that age, sex, vertical jump height, leg power, number of pull ups completed, kilograms pulled, number of push-ups completed and VO_{2max} were significantly associated with experiencing MSI (Table 5.2). The multivariate logistic regression analysis indicated that the main effects model that was significant and best described increased injury risk included decreased age, female sex, decreased number of pull ups, and increased VO_{2max} (Table 5.3). The predictor variables in the final model were centered around the mean. The measure of effect of VO_{2max} on injury was significantly modified by sex so the interaction between sex and VO_{2max} was also included in the final model. For one unit increase in VO_{2max}, females were 1.59 times more likely to have an injury whereas males were 0.97 times less likely to have an injury.

Table 5.2 Univariate results from logistic regression

Variable	OR**	95% CI	p-Value
Age (years)*	0.51	0.44 – 0.59	<.0001
Sex (female)	1.48	1.03 - 2.12	0.034
Body Mass (Kg)	1.00	0.99 - 1.01	0.327
Body Fat (%)	0.99	0.97 - 1.02	0.510
Combined Grip (Kg)	1.01	1.00 - 1.01	0.061
Vertical Jump (Inches)	1.05	1.03 - 1.07	<.0001
Leg Power (Watts)	1.00	1.00 - 1.00	<.0001
Pull Ups (n)*	1.04	1.02 – 1.05	<.0001
Kg Pulled	1.00	1.00 - 1.00	<.0001
Push Up	1.04	1.02 - 1.05	<.0001
Vo_{2max} (ml/Kg/min)*	1.07	1.04 - 1.09	<.0001
Plank Time (minutes)	1.15	0.99 - 1.32	0.636

*mean centered
**OR per increase in variable unit

Table 5.3 Results from the multivariate logistic regression

Variable	Odds Ratio	95% Confidence Limits
Age*	0.55	0.50 - 0.61
Sex (Female)	1.77	0.56 - 5.58
Pull Ups* (n)	0.99	0.96 - 1.02
VO_{2max}*		
Male	0.97	0.92 - 1.32
Female	1.59	1.02 - 1.91

*mean centered

5.4 Discussion

The objective of this study was to determine the relationship between several fitness test scores and the risk of musculoskeletal injury in a group of municipal police officers in Western Canada. A multivariate regression indicated that a combination of decreased age, female sex, decreased number of pullups, and increased VO_{2max} best explained increased injury risk. Additionally, the findings indicated an interaction between sex and VO_{2max} so the effect of VO_{2max} on injury risk cannot be understood without accounting for sex.

Some police studies have found that officers who engage in fitness training, were less likely to experience an injury reportable to occupational health (17) and police officers with the highest self-reported fitness levels were less likely to experience sprains or strains than those who considered themselves less fit (37). In contrast, it has also been reported that police officers who collected workers' compensation were more fit than those who did not (19). The conflicting findings could be due to several factors including methodological factors and varying definitions of fitness level, physical activity level, and/or injury. The current study found that an increased fitness level, increased VO_{2max}, was a risk factor for injury within females. However, this finding should be further investigated. Research investigating the mechanism of injury in police, military, and firefighters has highlighted that participation in sport or fitness activities is a common mechanism for injury in these groups and account for approximately 30% of non-work-related injuries (21,23,79,80). Other injury research involving healthy adults indicates that participating in physical activity, including higher volumes of aerobic exercise (300 min/week-1), is associated with an increased risk of both acute MSI and recurrent MSI (81) and that the risk of sustaining an activity-related injury is increased with higher duration of physical activity per week (82). The proportion of healthy men and women with activity-related injury also increased with higher cardiovascular fitness levels and highly fit men had almost four times the risk of MSI compared to that of men in the lowest cardiorespiratory fitness category (82).

Nabeel *et.al.* (2007) classified people with a high level of physical activity as exercising at least 30 minutes twice per week (37) and found that police officers who were more physically active were more resistant to injury. However, this definition of activity does not even meet the "low-dose aerobic exercise" definition used by Brown *et.al* (2017) who found a dose response relationship between physical activity and injury risk (81). Given that increased physical activity (in duration and intensity) increases cardiorespiratory fitness (i.e. VO_{2max}), this may explain the conflicting information regarding the relationship between physical activity and injury as well as the association between increased VO_{2max} and injury risk observed in this study. It may be exposure to the exercise that increased injury risk, rather than injury being a result of high cardiovascular fitness.

Very little research has investigated the relationship between pull ups and occupational injury. Two studies involving male military trainees (83,84) and one examining Federal Bureau of Investigation trainees (21) concluded that there was no association between the number of pull ups performed and MSI risk. Another study indicated a significant univariate association between increased pull ups completed and a decreased risk of MSI in male and female British army recruits (85). In a more recent study, Swedish Armed Forces marines entering the training course who performed fewer than four pull-ups were at increased risk for lower back pain (HR 1.9, 95% CI 1.2 to 3.0) (86). No studies were located investigating this relationship in active duty police officers or police recruits. In the current study, an increased number of completed pull ups was indicated in the main effects model as being protective of injury (OR 0.89, 95% CI 0.80 to 0.98) however, this significance disappeared in the interaction model.

Increased age has been found to be a risk factor for injury in the general working population (87–89). However, for police officers, this does not appear to be reflected as increased age appears to be a protective factor for injury (2,14,31). This was also indicated in the current study where increased age was associated with a decreased injury risk (OR 0.55; 95% CI 0.50-0.61). This decreased risk with increased age may be a proxy for the task differences between junior and senior police officers.

Police officers' work-related injuries primarily occur when apprehending and detaining a noncompliant or assaultive suspect (18) and can account for 31.5% to 61.7% of officer injuries (22,23). The likelihood of apprehending suspects is related to the position in which an officer works. Officers working in front line positions (i.e., patrol) are more likely to apprehend suspects than those working in more investigative or administrative areas. In the participating police agency, patrol is the first position that new officers work in once they finish recruit training and often remain there for a minimum of 3 to 5 years. Research supports that it is during these first 5 years that police officers are most likely to get injured at work (17). This is likely why younger police officers and those with fewer years of service are more likely to become injured; because their daily duties put them at increased risk for injury through greater exposure to suspects and the opportunity to arrest them. The number of years served was not included in the analysis because there was a high correlation with age it's strong relationship with injury. The main research question was examining the relationship between fitness and injury, but years of service cannot be entirely ignored. It has also been suggested that the risk of injury associated with age is different between sexes. In a previous study examining the relationship between sex, age and injury, younger females (age 20-29) had more time loss claims but this difference was modified for older police officers. At age 30, as age increased males continued to have a greater proportion of injuries compared to females (4). The current study did not identify a significant interaction between age and sex in relation to injury ($p=0.15$).

Overall, the relationship between sex and injury potential in police has not been well investigated. This may be due to females being a minority in this occupation. For example, in 2017, only 12.5% of law-enforcement officers in the United States were female (90) whereas in Canada, females accounted for 21% of all sworn officers during this same time (77). As more women enter policing, the number of female police officers who are hurt on the job appears to increase (4). However, as the number of female police officers is generally low, small changes can result in large percentage changes falsely indicating that females are more likely to become injured than males. Proper comparisons and careful evaluation of data need to be made. It is possible that the increased likelihood of injury for females may not be related to their roles or performance as police officers but to other activities external to their job such as sport or fitness activities (79,91).

A limitation of this study, which is common to studies using secondary data, is that the information was recorded for a reason other than research. Additionally, there was no information regarding the mechanism of injury. Though the injuries recorded affected the police officer's ability to work at full capacity, information regarding how the officer became injured was not available.

The definition of injury can influence the apparent relationship between fitness measures and injury in police officers. In this study, and the literature referred to in this paper, we have referred to MSI. MSI involve damage to bone, ligaments, tendons, muscle and cartilage. In research injures are identified through self-report (37,79), workers' compensation claims (17), or reports to the employer (80,92). Injuries that occur during physical activity may or may not be reported to workers' compensation but may be reported to the employer if the injured worker is not able to work to their full capacity. This lack of a common definition limits the ability to directly compare study results.

5.5 Conclusion

The objective of this study was to determine the relationship between several fitness test scores and risk of musculoskeletal injury in a group of municipal police officers in Western Canada. A multivariate regression indicated that a combination of age, sex, number of pull ups completed and VO_{2max} best explained injury risk. Additionally, the findings indicated an interaction between sex and VO_{2max}, so the effect of VO_{2max} on injury risk cannot be understood without accounting for sex. Females with a $VO_{2max} \geq 35$ ml/kg/min may be at increased risk of injury. However, the injury may not be related to work tasks but rather sporting or fitness activities. This needs to be examined further by analysing the relationship between the mechanisms of injury and fitness components. Including the analysis of injury mechanism would also clarify the relationship between fitness and work-related injury. The fitness tests included in this study were general fitness tests. Examining the relationship between occupational specific fitness test performances in relation to work-related injury is also recommended. Looking in more detail at the relationships between injury mechanism, fitness and occupational specific fitness performance will add insight into prevention strategies.

Chapter 6: Conclusion

6.1. Main Findings

The rationale and objectives of this thesis are outlined in the introductory chapter along with the significance of the studies presented in chapters 3, 4 and 5. The following discussion summarizes the general results and the importance of the findings. Future directions will also be discussed.

The second chapter summarized existing information regarding MSI suffered by police officers and revealed that MSI has varied definitions in the literature. For the purpose of this thesis, MSI include sprains, strains, fractures, dislocations, cartilage damage and non-specific joint or regional pain (i.e., knee pain, back pain, etc.). It is clear that MSI are the most common injury type among police officers and they often occur through bodily reaction, physical exertion and violent acts (4) related to suspect apprehension and/or resistance (14,16,22). There is some inconsistency regarding the most commonly injured body part which could be due to different study methods and data sources. Studies that evaluated workers' compensation data indicated that the upper extremities were injured most frequently (31,33) however; studies using medical data showed that the lower extremities and back (14,21,34) or the shoulder (36) were common injury sites.

Several modifiable and non-modifiable elements were identified in the multifactorial cause of injury in police work. Officer safety training and equipment can influence the risk of MSI. Several use of force options are available to a police officer when they encounter a resistive or assaultive subject. These options include oleoresin capsaicin (OC) spray, batons, and conductive energy devices (CED). Injury risk to police officers during use of force events was reduced when a CED was used in comparison to cases where no CED was used (10). Monthly incidence of injury in police declined significantly, by 25% to 62%, after adoption of CED devices (24).

Increased physical activity and physical fitness were associated with decreased injury in police officers (37). Compared to those with a lower self-reported fitness level, police officers who reported a high level of fitness were less likely to experience back pain (OR 0.48, 95% CI 0-09-0.88) and were less likely to report back pain (OR 0.37, 95% CI 0.10-0.73) (37).

The third chapter continued to investigate the relationship between physical fitness and musculoskeletal injuries in public safety personnel (i.e., police officers, firefighters and paramedics) through a systematic review of the literature. The research in this area was found to be very limited as only eleven studies met the inclusion criteria described in the review and 4 of these included police officers. These studies were deemed moderate to high in methodological quality according to the Newcastle-Ottawa Scale. Unfortunately, the limited number of studies available were heterogenous in terms of observation period, number of participants, and measures of fitness, making comparison between studies difficult. One-year injury incidence for firefighters ranged from 11.2 to 30.4 injuries per 100 firefighters (51,80). Firefighter trainees had a higher yearly incidence of injury at 97.7 injuries per 100 full-time trainees and 15.8 injuries per 100 part-time trainees (55). Police trainees also demonstrated high injury incidence being between 60.8 to 101.8 injuries per 100 trainees per year (56,58), whereas career police officers end elite officers had rates of 5.2 and 22.0 injuries per 100 police officers per year(54,93). Because of differing definitions of injury case across studies, these incidence rates are not comparable. Another reason that these studies cannot be compared directly is because tasks between public safety personnel occupational groups differ greatly as does injury risk.

The synthesis of findings provided some evidence for an association between physical fitness test scores and injury risk. A consistent trend was found between lower levels of aerobic fitness and increased injury risk and higher economic cost of injury (32,52,55). There was conflicting evidence regarding the relationship between body composition and injury risk, where one study found no association (51) and another found that increased body mass index was a significant positive predictor of MSI in firefighters (53).

Chapter four provides a descriptive analysis of the epidemiology of MSI occurring over a period of 41 months between January 01, 2013 and June 02, 2016 in police officers employed by a municipal police service in Edmonton, Alberta. Male and female police officers experienced similar risk of injury (OR 1.05, 95% CI 0.79-1.40). The proportion of MSI that were sprains and strains was higher than that found in previous research at 89.2% (14,16,22,23). Consistent with other studies, the back (34,35), shoulder (20) and lower extremities (31,33) were most frequently injured and accounted for 19.2% and 13.5% of all MSI, respectively. Hands and finger, ankles, and knees respectively accounted for 12.1%, 11.3% and 11.3% of injuries. Most injured police officers were uniformed, patrol/beat officers (68.3%). The prevalence of injury by other work areas did not differ significantly (p=0.62) and proportions ranged from 25%-48% with administrative and support staff demonstrating the greatest proportion of injuries.

Chapter five examined the relationship between physical fitness test scores through a matched case control study using logistic regression. Pre-existing fitness and medical data were used for the analysis. With the exception of McGill *et al.*(54), much research has only compared injury risk to 1 or 2 fitness measures at a time, not in concert. A unique aspect of this study was the inclusion of several fitness measures including body fat percentage, hand grip strength, vertical jump height, leg power, pull-ups, kilograms pulled, push ups, plank time, and maximal relative oxygen consumption (VO_{2max}). The multivariable regression indicated that a combination of decreased age, female sex, decreased number of pullups and increased VO_{2max} best explained injury risk. The findings also indicated an interaction between sex and VO_{2max} so the effect of VO_{2max} on injury risk cannot be understood without accounting for sex. While the relationship between VO_{2max} and injury is relatively weak for males (OR 0.97, 95% CI 0.92-1.02) for females, an increase in VO_{2max} has a much stronger association with increased injury risk (OR 1.59, 95% CI 1.32-1.91). This interaction is a unique finding which needs to be explored further in future research.

6.2 Methodological Issues

While previous studies have examined the occurrence of injury in police officers (14,16,35–37,94–96,19,21–23,30,31,33,34), only some have included a definition of injury (20,21,34,36). Once definitions are included, they vary in terms of the scope of injury covered. For example, the range of injury definition in the literature ranges from a broad definition like major or minor physical harm (23), to a more specific definition like any case of disability in which the diagnosis was in the domain of musculoskeletal disease of the upper or lower extremities, neck or trunk, including skeletal/joint impairments or limitation of motion, muscle injuries, peripheral neuritis or neuralgia (34). This may explain the range of incidence rates among the literature where the incidence ranges from 240 to 2280 injuries per 1000 police officers, per year (19,31). Clearly, comparing results is difficult. The source of injury data varies as well and can be from workers' compensation data (19), medical data (21), or self-report (37). This would also affect study results. This thesis identified that a specific definition of injury may decrease the comparability of the results across studies but lends for a clearer understanding of what is being examined. Ideally, future studies will use a standardized, consistent definition of injury.

Further, studies examining the relationship between physical fitness and injury in the police population used varying methods to determine physical fitness including self-report (37,45), retrospective data analysis (56,58), and direct measure (54). The studies that used self-report measured physical activity rather than physical fitness as no fitness test results were obtained. Instead, the data gained from self-report reflected the type and frequency of physical activity conducted by study participants. While not only being affected by recall and reporting bias, this self-report data did not reflect physical fitness scores.

The data for Chapters 4 and 5 were obtained from the municipal police service and was administrative data. Using administrative data can be advantageous in that information on many individuals is already compiled. This removes the time needed for data collection and can also allow for a larger study population at a low cost. However, there are inherent limitations when administrative data is used. For example, there is no way to identify the accuracy of the records as access to neither the individuals nor their medical records is possible. The data used in this study was primarily gathered for organizational need and administrative purposes. The implications of this in regard to this study are that data was missing and that data such as mechanism of injury was not able to be linked with the medical and fitness data.

Work area (i.e., patrol officer, administrative support, etc.) was recorded in both the fitness and the medical data. In the fitness data, the work area was recorded at the time of fitness testing, so it is possible that the individuals were not working in the same area when they were injured, which occurred sometime after the fitness test. The accuracy of work area in the medical data is more questionable. In surveying the medical data set it was observed that several individuals were recorded as being on leave. This data set likely updated the individual's work area over time and therefore does not accurately reflect the work area at the time of injury. The subgroup analysis in chapter 3 (n=293 subjects) used the work area data from the fitness data set as it was deemed more likely to reflect the work area at the time of injury. This was because all individuals were active police officers at the time of fitness testing and testing occurred just prior to injury so temporality of work area prior to injury was established. However, we recognize there is likely some inaccuracy in the work area data.

A unique aspect of this thesis is the capture of injuries that affected an active police officer's ability to work at full capacity whether injured during their duties or while away from work. Unfortunately, data regarding the mechanism of injury was missing so occupational and non-occupational mechanisms of injury could not be categorized separately. This may not only affect the accuracy of injury incidence and its association with policing, but it also limits the ability to provide recommendations for injury prevention. Though the police service recorded some information on injury mechanisms, this was recorded only to examine trends and did not contain unique individual identifiers so it could not be linked with the medical and fitness data. Some injuries were associated with fitness activities, which may explain why increased VO_{2max} was associated with increased injury in female police officers. Increased exposure to physical activity would likely increase one's VO_{2max} while at the same time increasing exposure to repetitive and dynamic bodily motion. This increased exposure may increase injury risk leaving VO_{2max} as a proxy for exposure rather than a risk factor for injury.

6.3. Future directions

Future research would clearly benefit from more accurate data on police and public safety personnel. This would require improving data collection and linkage of agency-specific administrative information with other data sources such as workers' compensation and health care utilization datasets, which collect more detailed information on clinical injury diagnoses and related disability. The inclusion of data on mechanism of injury would be beneficial as it could be cross-referenced with injury type and body part to further inform targeted injury prevention strategies. One could then examine if there were associations between a certain mechanism of injury with the occurrence of injury to a specific body area, for example. Additionally, knowledge on injury mechanism could direct prevention strategies based on education or job modification. For example, if female police officers are consistently being injured by a specific exercise during physical training, education could be provided on proper technique or that exercise could be removed. Suspect apprehension is a common source of injury so if a certain aspect of apprehension is identified as having increased injury risk, then officer safety tactics or tools could be modified to decrease injury risk. Data on mechanism of injury is a valuable resource and it is recommended that police agencies consistently collect and record this information in their medical/injury data.

The inclusion of sex comparisons in future research is encouraged. The number of female police officers is continually increasing. For example, the proportion of female police officers in Canada has grown from 4% in 1986 to 22% in 2018 (97). Chapter 3 indicated that the proportion of injured male and female officers was not significantly different than the general police population. Other research has indicated that differences in injury rates between the sexes was not significantly different (21,31). However, injured body sites and injury type appear to differ between males and females and further investigation is required to determine whether differences are due to sex differences or police-related activities.

The information in the literature about injuries and health outcomes among law enforcement is sparse. The reason why more research is available regarding health and injuries for the fire service is unknown (98). Perhaps law enforcement has not suffered an occupational-specific health crisis as in the fire service where the risk of cancer is increased and likely associated to their occupational exposures (99). Given the high incidence rates of MSI in police officers outlined in this thesis, we proposed that MSI is a health crisis for police officers. Admittedly, the likelihood of death from MSI is low, but factors such as impact on the community, the police agency and individual officers need to be considered. There is a gap in knowledge regarding the occurrence of MSI in police officers and an even greater gap relating to factors that contribute to these injuries. Increasing the volume and quality of research in the area of police officer injury and the relationship with physical fitness is extremely important.

The community depends on police officers to keep order, prevent crime, and maintain a safe community. If police officers are unable to do their jobs effectively because of injury, it is not only the officers that suffer but their organization and community as well. Police officers choose to serve their communities and do a job that many people do not want to do. This puts them at risk for harm. The onus is on the health research community to increase knowledge regarding the unique health risks that police officers face and to develop strategies to improve the overall wellbeing of those who serve them. Further research is also needed to evaluate whether injures to the common sites can be reduced though increased stabilization exercises, positional awareness, and whole body balance in addition to traditional strength training as is done as part of athletic injury prevention (100,101). Learning the perspective of police officers and other public safety personnel related to being in a performance occupation (like athletes) could also inform how training and health maintenance is approached in these populations.

6.4 Summary

In summary, this thesis indicates that police officers suffer MSI frequently and that sprains and strains dominate. The lower extremity, back, and/or shoulder are most commonly injured in this population. Further, fitness components including the number of pull ups and aerobic capacity along with sex and age were found to best describe injury risk in a group of municipal police officers.

References

1. Tiesman HM, Gwilliam M, Konda S, Rojek J, Marsh S. Nonfatal Injuries to Law Enforcement Officers: A Rise in Assaults. Am J Prev Med [Internet]. 2018;54(4):503–9. Available from: http://dx.doi.org/10.1016/j.amepre.2017.12.005

2. Gray SE, Collie A. The nature and burden of occupational injury among first responder occupations: A retrospective cohort study in Australian workers. Injury [Internet]. 2017 Nov 1 [cited 2018 Aug 8];48(11):2470–7. Available from: https://www-sciencedirect-com.login.ezproxy.library.ualberta.ca/science/article/pii/S0020138317306319

3. Lentz L, Randall JR, Gross DP, Senthilselvan A, Voaklander D. The relationship between physical fitness and occupational injury in emergency responders: A systematic review. Am J Ind Med [Internet]. 2019;62(1):3–13. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22929

4. Cohen IM, Garis L. Determinants of Injury and Death in Canadian Police Officers [Internet]. 2018. Available from: https://cjr.ufv.ca/wp-content/uploads/2018/09/Determinants-of-Injury-and-Death-in-Police-Officers-August-2018.pdf

5. US Bureau of Labor Statistics. Fact Sheet, Police Officers. 2016.

6. Fekedulegn D, Burchfiel CM, Ma CC, Andrew ME, Hartley TA, Charles LE, et al. Fatigue and on-duty injury among police officers: The BCOPS study. J Safety Res. 2017;

7. Tiesman HM, Hendricks SA, Bell JL, Amandus HA. Eleven years of occupational mortality in law enforcement: The census of fatal occupational injuries, 1992-2002. Am J Ind Med [Internet]. 2010 Jun 17 [cited 2019 Mar 6];53(9):940–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20564516

8. Konda S, Reichard AA, Tiesman HM. Occupational Injuries among U.S. Correctional Officers, 1999– 2008. J Saf Res [Internet]. 2012;43(3):181–6. Available from: http://www.bls.gov/iif/oshcfoil.htm.

9. Castillo EM, Prabhakar N, Luu B. Factors associated with law enforcement-related use-of-force injury. Am J Emerg Med [Internet]. 2012;30(4):526–31. Available from: http://dx.doi.org/10.1016/j.ajem.2011.01.017

10. Paoline EA, Terrill W, Ingram JR. Police Use of Force and Officer Injuries: Comparing Conducted Energy Devices (CEDs) to Hands- and Weapon-Based Tactics. Police Q. 2012;15(2):115–36.

11. Jenkinson E, Neeson C, Bleetman A. The relative risk of police use-of-force options: Evaluating the potential for deployment of electronic weaponry. J Clin Forensic Med [Internet]. 2006 Jul 1 [cited 2019 Mar 6];13(5):229–41. Available from: https://www.sciencedirect.com/science/article/pii/S1353113105001999

12. White MD, Dario LM, Shjarback JA. Assessing dangerousness in policing: An analysis of officer deaths in the United States, 1970–2016. Criminol Public Policy. 2019;18(1):11–35.

13. Benoit AC, Cotnam J, Raboud J, Greene S, Beaver K, Zoccole A, et al. Experiences of chronic stress and mental health concerns among urban Indigenous women. Arch Womens Ment Health [Internet]. 2016;19(5):809–23. Available from: http://dx.doi.org/10.1007/s00737-016-0622-8

14. Reichard AA, Jackson LL. Occupational injuries among emergency responders. Am J Ind Med. 2010;

15. Suyama J, Rittenberger JC, Patterson PD, Hostler D. Comparison of public safety provider injury rates. Prehospital Emerg Care. 2009;13(4):451–5.

16. Brandl SG, Stroshine MS. The Physical Hazards of Police Work Revisited. Police Q. 2012;15(3):262–82.

17. International Assoc of Chiefs of Police United States of America. Reducing Officer Injuries Final Report: A Summary of Data Findings and Recommendations from a Multi-Agency Injury Tracking Study. 2013.

18. Lyons K, Radburn C, Orr R, Pope R. A profile of injuries sustained by law enforcement officers: A critical review. Int J Environ Res Public Health. 2017;14(2).

19. Boyce RW, Hyatt AR, Jones GR. Workers' compensation claims and physical fitness capacity of police officers. Health Values. 1992;16(4):22–9.

20. Cho T-S, Jeon W-J, Lee J-G, Seok J-M, Cho J-H. Factors Affecting the Musculoskeletal Symptoms of Korean Police Officers. J Phys Ther Sci [Internet]. 2014;26(6):925–30. Available from: http://jlc.jst.go.jp/DN/JST.JSTAGE/jpts/26.925?lang=en&from=CrossRef&type=abstract

21. Knapik JJ, Grier T, Spiess A, Swedler DI, Hauret KG, Graham B, et al. Injury rates and injury risk factors among federal bureau of investigation new agent trainees. BMC Public Health. 2011;11(920).

22. Brandl, Steven G. Stroshine MS, Brandl SG, Stroshine MS. Toward and Understanding of the Physical Hazards of Police Work. Police Q. 2003;6(2):3–6.

23. Larsen B, Aisbett B, Silk A. The injury profile of an Australian specialist policing unit. Int J Environ Res Public Health. 2016;

24. MacDonald JM, Kaminski RJ, Smith MR. The effect of less-lethal weapons on injuries in

police use-of-force events. Am J Public Health. 2009;

25. Hougland S, Mesloh C, Henych M. Use of forc, civil litigation, and the taser. One agency's experience. FBI Law Enforc Bull. 2005;74(3):24–30.

26. Brandl SG, Stroshine MS. Toward an Understanding of the Physical Hazards of Police Work. Police Q. 2003;

27. The Canadian Association of Chiefs of Police. A National Use of Force Framework. 2000.

28. Alpert GP, Dunham RG. Policy and Training Recommendations Related to Police Use of CEDs: Overview of Findings From a Comprehensive National Study. Police Q [Internet]. 2010 Sep 21 [cited 2019 Mar 6];13(3):235–59. Available from: http://journals.sagepub.com/doi/10.1177/1098611110373993

29. Violanti JM, Fekedulegn D. Shift work and the incidence of injury among police officers. Am J Ind Med. 2012;55(2):217–27.

30. Violanti JM, Fekedulegn D, Andrew ME, Charles LE, Hartley TA, Vila B, et al. Shift work and long-term injury among police officers. Scand J Work Environ Heal. 2013;39(4):361–8.

31. Sullivan CSB, Shimizu KT. Epidemiological studies of work-related injuries among law enforcement personnel. Occup Med (Chic Ill). 1988;

32. Boyce, Robert W. Hiatt A. Physical fitness of police officers as they progress from supervised recruit to unsupervised. Wellness Perspect. 1992;8(4):31.

33. Holloway-Beth A, Forst L, Freels S, Brandt-Rauf S, Friedman L. Occupational injury surveillance among law enforcement officers using workers' compensation data, Illinois 1980 to 2008. J Occup Environ Med. 2016;

34. Jahani MR, Motevalian SA, Asgari AR. Musculoskeletal disabilities among police force personnel of the Islamic Republic of Iran. Mil Med. 2002;167(10) :(pp 850-852), 2002. Date of Publication: 01 Oct 2002.):852.

35. Gyi DE, Porter JM. Musculoskeletal problems and driving in police officers. Occup Med (Chic Ill). 1998;48(3):153–60.

36. Rhee HY, Cho JH, Seok JM, Cho TS, Jeon WJ, Lee JG, et al. Prevalence of musculoskeletal disorders among Korean police personnel. Arch Environ Occup Heal. 2015;

37. Nabeel I, Baker BA, McGrail MP, Flottemesch TJ. Correlation between physical activity, fitness, and musculoskeletal injuries in police officers. Minn Med. 2007;

38. McGill S, Frost D, Lam T, Finlay T, Darby K, Andersen J. Fitness and movement quality of emergency task force police officers: An age-grouped database with comparison to populations of emergency services personnel, athletes and the general public. Int J Ind Ergon [Internet]. 2013;43(2):146–53. Available from: http://dx.doi.org/10.1016/j.ergon.2012.11.013

39. McKinnon CD, Callaghan JP, Dickerson CR. Field quantification of physical exposures of police officers in vehicle operation. Int J Occup Saf Ergon. 2011;17(1):61–8.

40. McKinnon CD, Callaghan JP, Dickerson CR. Evaluation of the influence of mobile data terminal location on physical exposures during simulated police patrol activities. Appl Ergon [Internet]. 2012;43(5):859–67. Available from: http://dx.doi.org/10.1016/j.apergo.2011.12.009

41. Holmes MWR, McKinnon CD, Dickerson CR, Callaghan JP. The effects of police duty belt and seat design changes on lumbar spine posture, driver contact pressure and discomfort.

Ergonomics. 2013;

42. Wong IS, Mcleod CB, Demers PA, Scandinavian S, January N. Shift work trends and risk of work injury among Canadian workers. Scand J Work Environ Heal. 2011;37(1):54–61.

43. Barker K. Tracking officer injuries: A Chief's duty. The Police Chief. 2012;79(14).

44. Szubert Z, Sobala W. Work-related injuries among firefighters: sites and circumstances of their occurrence. Int J Occup Med Environ Health [Internet]. 2002 [cited 2019 Mar 6];15(1):49–55. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12038864

45. International Association of Chiefs of Police. Reducing Officer Injuries: Final Report. 2013; Available from: http://www.theiacp.org/portals/0/pdfs/IACP_ROI_Final_Report.pdf

46. Bushman TT, Chervak M, Anderson M JB. Association of physical fitness assessments and injury risk among US army soldiers. Med Sci Sports Exerc. 2013;45(5):396.

47. Teyhen DS, Shaffer SW, Butler RJ, Goffar SL, Kiesel KB, Rhon DI, et al. What Risk Factors Are Associated With Musculoskeletal Injury in US Army Rangers? A Prospective Prognostic Study. Clin Orthop Relat Res. 2015;473(9):2948–58.

48. Sulsky SI, Bulzacchelli MT, Zhu L, Karlsson L, McKinnon CJ, Hill OT, et al. Risk Factors for Training-Related Injuries during U.S. Army Basic Combat Training. Mil Med. 2018;183:55–65.

49. Higgins JT, Alderson P, Clarke M, Mulrow CD ,Oxman AD. Cochrane Handbook for Systematic Reviews of Interventions : Cochrane Book Series - cochrane-handbook-for-systematic-reviews-of-interventions.pdf. A John Wiley & Sons, Ltd., Publication. 2011.

50. Jahnke SA, Carlos Poston WS, Haddock CK, Jitnarin N. Injury among a population based

sample of career firefighters in the central USA. Inj Prev. 2013;19(6):393–8.

51. Poplin GS, Roe DJ, Burgess JL, Peate WF, Harris RB. Fire fit: assessing comprehensive fitness and injury risk in the fire service. Int Arch Occup Environ Health. 2016;89(2):251–9.

52. Poplin GS, Roe DJ, Peate W, Harris RB, Burgess JL. The association of aerobic fitness with injuries in the fire service. Am J Epidemiol. 2014;

53. Jahnke SA, Poston WSC, Haddock CK, Jitnarin N. Obesity and incident injury among career firefighters in the central United States. Obesity. 2013;21(8):1505–8.

54. McGill S, Frost D, Lam T, Finlay T, Darby K, Cannon J. Can fitness and movement quality prevent back injury in elite task force police officers? A 5-year longitudinal study. Ergonomics [Internet]. 2015;58(10):1682–9. Available from: http://dx.doi.org/10.1080/00140139.2015.1035760

55. Wynn P, Hawdon P. Cardiorespiratory fitness selection standard and occupational outcomes in trainee firefighters. Occup Med (Chic Ill). 2012;

56. Orr R, Pope R, Peterson S, Hinton B, Stierli M. Leg power as an indicator of risk of injury or illness in police recruits. Int J Environ Res Public Health. 2016;13(2).

57. Cady LD, Bischoff DP, O'Connell ER, Thomas PC, Allan JH. Strength and fitness and subsequent back injuries in firefighters. J Occup Med [Internet]. 1979 Apr [cited 2019 Nov 3];21(4):269–72. Available from: http://www.ncbi.nlm.nih.gov/pubmed/438917

58. Orr R, Pope R, Stierli M, Hinton B. Grip strength and its relationship to police recruit task performance and injury risk: A retrospective cohort study. Int J Environ Res Public Health. 2017;14(8).

59. Fulton J, Wright K, Kelly M, Zebrosky B, Zanis M, Drvol C, et al. Injury risk is altered by previous injury: a systematic review of the literature and presentation of causative neuromuscular factors. Int J Sports Phys Ther [Internet]. 2014;9(5):583–95. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25328821%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4196323

60. Butler RJ, Contreras M, Butron L, Plisky PJ, Kiesel KB. Functional Movement Screen and Physical Performance Scores During a Firefighter Academy: Implications for Injury Screening. Med Sci Sport Exerc. 2011;43(Suppl 1):795.

61. Studnek JR, Crawford J Mac. Factors associated with back problems among emergency medical technicians. Am J Ind Med. 2007;50(6):464–9.

62. Letafatkar A, Hadadnezhad M, Shojaedin S, Mohamadi E. Relationship between functional movement screening score and history of injury. Int J Sports Phys Ther [Internet]. 2014;9(1):21–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24567852%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC3924605

63. O'Connor FG, Deuster PA, Davis J, Pappas CG, Knapik JJ. Functional movement screening: Predicting injuries in officer candidates. Med Sci Sports Exerc. 2011;43(12):2224–30.

64. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. N Am J Sports Phys Ther [Internet]. 2010;5(2):47–54. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21589661%0Ahttp://www.pubmedcentral.nih.go

v/articlerender.fcgi?artid=PMC2953387

65. Knapik J Oseph J K, Cosio-Lima Ludimila M, Reynolds Katy L SRS. Efficacy of Functional Movement Screening in Predicting Injuries in Coast Guard Cadets. J Strength Cond Res. 2015;29(5):1157–62.

66. Butler RJ, Contreras M, Burton LC, Plisky PJ, Goode A, Kiesel K. Modifiable risk factors predict injuries in firefighters during training academies. Work. 2013;46(1):11–7.

67. Cady LD, Thomas PC, Karwasky RJ. Program for increasing health and physical fitness of fire fighters. Vol. 27, Journal of Occupational Medicine. 1985. p. 110–4.

68. Statistcs Canada. Police personnel and selected crime statistics, municipal police services. 2018.

69. Shannon HS, Lowe GS. How many injured workers do not file claims for workers' compensation benefits? Am J Ind Med. 2002;

70. Anderson GS. Police officer physical ability testing Re-validating a selection criterion. Policing. 2001;24(1):8–31.

71. Vanhees L, Lefevre J, Philippaerts R, Martens M. How to assess physical activity ? How to assess physical fitness ? Eur J Cardiovasc Prev Rehabil. 2015;12(2).

72. Caspersen CJ, Christenson GM. Physical Activity, Exercise, and Physical Fitness: Definitions and Distinctions for Health-Related Research. Public Health Rep. 1985;100(2):126–31.

73. Salmon P. Effects of physical exercise on anxiety, depression, and sensitivity to stress: A unifying theory. Clin Psychol Rev. 2001;21(1):33–61.

74. Gebhardt, Deborah L., Crump CE. Employee Fitness and Wellness Programs in the

Workplace. - Western Michigan University (Alma). Am Psychol [Internet]. 1990;45(2):262–72. Available from: http://primo-pmtna01.hosted.exlibrisgroup.com/primo_library/libweb/action/display.do?frbrVersion=4&tabs=viewOnlineTab&ct=display&fn=search&doc=TN_ericEJ406366&indx=1&recIds=TN_ericEJ406366&recIdxs=0&elementId=0&renderMode=poppedOut&displayMode=full&frbrVe

75. Robbins R, Jackson CL, Underwood P, Vieira D, Jean-Louis G, Buxton OM. Employee Sleep and Workplace Health Promotion: A Systematic Review. Am J Heal Promot. 2019;33(7):1009–19.

76. Mead G, Morley W, Campbell P, Greig C, Mcmurdo M, Lawlor D. Exercise for depression (Review). Cochrane Collab. 2010;(3):1–51.

77. Conor P. Police resources in Canada , 2017 [Internet]. Vol. 38, Juristat. Statistics Canada; 2018. Available from: https://www150.statcan.gc.ca/n1/en/pub/85-002-x/2018001/article/54912-eng.pdf?st=98c2yXnV

78. Hosmer DW, Lemeshow S, May SM. Applied Survival Analysis: Regression Modeling of Time-to-Event Data. 2nd ed. Vol. 41, Technometrics. New York: Wiley; 2008.

79. Thériault FL, Gabler K, Naicker K. Health and Lifestyle Information Survey of Canadian Armed Forces Personnel 2013/2014 – Regular Force Report. Ottawa, Ontario, Canada; 2016.

80. Poplin GS, Harris RB, Pollack KM, Peate WF, Burgess JL. Beyond the fireground: Injuries in the fire service. Inj Prev. 2012;

81. Brown JC, Schmitz KH. The Dose-Response Effects of Aerobic Exercise on Musculoskeletal Injury: A Post Hoc Analysis of a Randomized Trial. Res Sport Med.

2017;25(3):277–89.

82. Hootman JM, Macera CA, Ainsworth BE, Martin M, Addy CL, Blair N. Association among Physical Activity Level, Cardiorespiratory Fitness, and Risk of Musculoskeletal Injury. Am J Epidemiol. 2001;154(3):251–8.

83. Lisman P, O'Connor FG, Deuster PA, Knapik JJ. Functional movement screen and aerobic fitness predict injuries in military training. Med Sci Sports Exerc. 2013;45(4):636–43.

84. Taanila H, Suni JH, Kannus P, Pihlajamäki H, Ruohola JP, Viskari J, et al. Risk factors of acute and overuse musculoskeletal injuries among young conscripts: A population-based cohort study Epidemiology of musculoskeletal disorders. BMC Musculoskelet Disord [Internet]. 2015;16(1). Available from: ???

85. Blacker SD, Wilkinson DM, Bilzon JLJ, Rayson MP. Risk Factors for Training Injuries among British Army Recruits. Mil Med. 2008;173(3):278–86.

86. Monnier A, Larsson H, Nero H, Djupsjöbacka M, Äng BO. A longitudinal observational study of back pain incidence, risk factors and occupational physical activity in Swedish marine trainees. BMJ Open. 2019;9(5):1–14.

87. Kenny GP, Yardley JE, Martineau L, Jay O. Physical work capacity in older adults: Implications for the aging worker. Am J Ind Med. 2008;51(8):610–25.

88. Buckwalter JA, Woo S. Age-related changes in ligaments and joint capsules: Implications for participation in sports. Spors Med Arthrosc Rev. 1996;4:250–62.

89. Bande R, López-Mourelo E. The Impact of Worker's Age on the Consequences of Occupational Accidents: Empirical Evidence Using Spanish Data. J Labor Res.

2015;36(2):129–74.

90. U.S. Department of Justice. Crime in the United States, 2017. Uniform Crime Report. 2018.

91. De Loës M, Jansson B. Work-related acute injuries from mandatory fitness training in the Swedish Police Force. Int J Sports Med. 2002;23(3):212–7.

92. Clompus SR, Albarran JW. Exploring the nature of resilience in paramedic practice: A psycho-social study. Int Emerg Nurs [Internet]. 2016 Sep 1 [cited 2018 Aug 8];28:1–7. Available from: https://www-sciencedirect-com.login.ezproxy.library.ualberta.ca/science/article/pii/S1755599X15001317

93. Boyce RW, Perko MA, Jones GR, Hiatt AH, Boone EL. Physical fitness, absenteeism and workers' compensation in smoking and non-smoking police officers. Occup Med (Chic Ill). 2006;

94. Himmelmann K. Putting prevention into practice for the benefit of children and young people with cerebral palsy. Arch Dis Child. 2018;103(12):1100–1100.

95. Burton AK, Tillotson KM, Symonds TL, Burke C MT. Occupational Risk Factors for the First-Onset and Subsequent Course of Low Back Trouble. Spine (Phila Pa 1976). 1996;21(22):2612–20.

96. Ramstrand N, Larsen LB. Musculoskeletal injuries in the workplace : perceptions of Swedish police. Int J Police Sci Manag. 2012;14(4):334–42.

97. Conor P, Robson J, Marcellus S. Police resources in Canada , 2018. Juristat [Internet]. 2019;(85):2–35. Available from: https://www150.statcan.gc.ca/n1/pub/85-002-x/2019001/article/00015-eng.htm

98. LaTourrette T, Loughran DS, Seabury SA. Occupational Safety and Health for Public Safety Employees Assessing the Evidence and the Implications for Public Policy [Internet]. Education. Santa Monica, CA: RAND Corporation; 2008. 33–40 p. Available from: http://www.silversands.co.uk/add_downloads/stannah.pdf

99. LeMasters GK, Genaidy AM, Succop P, Deddens J, Sobeih T, Barriera-Viruet H, et al. Cancer risk among firefighters: A review and meta-analysis of 32 studies. J Occup Environ Med. 2006;48(11):1189–202.

100. Hewett TE, Torg JS, Boden BP. Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. Br J Sports Med. 2009;43(6):417–22.

101. Hübscher M, Zech A, Pfeifer K, Hänsel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: A systematic review. Med Sci Sports Exerc. 2010;42(3):413–21.

102. Hoffmann MD, Colley RC, Doyon CY, Wong SL, Tomkinson GR, Lang JJ. Normative-referenced percentile values for physical fitness among Canadians. Heal Reports. 2019;30(10):14–22.

103. Messing K, Stock S, Tissot F. Work exposures and musculoskeletal disorders: how the treatment of gender and sex in population-based surveys can affect detection of exposure-effect relationships. In: Cohen S, Banister E, editors. What a difference sex and gender make: A Gender, Sex and Health Research Casebook. Vancouver, BC; 2012. p. 42–50.

Appendices

Appendix I

NEWCASTLE - OTTAWA QUALITY ASSESSMENT SCALE COHORT STUDIES

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability

Selection

1) Representativeness of the exposed cohort

a) truly representative of the average _______________ (describe) in the community ☐

b) somewhat representative of the average ______________ in the community ☐

c) selected group of users eg nurses, volunteers

d) no description of the derivation of the cohort

2) Selection of the non exposed cohort

a) drawn from the same community as the exposed cohort ☐

b) drawn from a different source

c) no description of the derivation of the non exposed cohort

3) Ascertainment of exposure

a) secure record (eg surgical records) ☐

b) structured interview ☐

c) written self report

d) no description

4) Demonstration that outcome of interest was not present at start of study

a) yes ☐

b) no

Comparability

1) Comparability of cohorts on the basis of the design or analysis

a) study controls for ______________ (select the most important factor) ☐

b) study controls for any additional factor ☐ (This criteria could be modified to indicate specific control for a second important factor.)

Outcome

1) Assessment of outcome

a) independent blind assessment ☐

b) record linkage ☐

c) self report

d) no description

2) Was follow-up long enough for outcomes to occur

a) yes (select an adequate follow up period for outcome of interest) ☐

b) no

3) Adequacy of follow up of cohorts

a) complete follow up - all subjects accounted for ☐

b) subjects lost to follow up unlikely to introduce bias - small number lost - > _____ % (select an adequate %) follow up, or description provided of those lost) ☐

c) follow up rate < _____% (select an adequate %) and no description of those lost

d) no statement

Appendix II

Description of Fitness Tests

Body Mass was measured and recorded in pounds and converted to kilograms as metric measures are required for calculations of maximal oxygen consumption and leg power.

Percent body fat was measured through bioelectric impedance using the *Inbody* 520 body composition analyzer. Bioelectric impedance sends a low-level electrical current though the body which travels at different speed through different body tissues. The rate at which the current passes through the body us used to calculate the body's fat free mass and thus the body fat percentage. Participants were given standard instructions regarding fluid and caffeine intake prior to doing the test.

Grip strength was measured bilaterally using a *Smedly* hand dynamometer 12-028IJ. The subject holds the dynamometer in the hand to be tested, with their elbow at a right angle by the side of the body. The base should rest on heel of palm and the handle should rest on middle of four fingers. When ready the subject squeezes the dynamometer with maximum effort for about 5 seconds. No other body movement is allowed. The highest measure of three tests for each hand was used and added together to get the grip strength value.

Vertical jump height was measured using a *Vertec* device which is comprised of plastic swivel vanes arranged in half-inch (1.25 cm) increments which are attached to a metal pole that can be adjusted to the test subject's reach height. It requires the subject to use their dominant hand to displace the highest possible vane with an overhead arm swing at the peak of their jump indicating the jump height.

Leg Power was calculated using the Sayers Equation which estimates peak power output (Peak Anaerobic Power output or PAPw) from the vertical jump;

$$PAPw\ (Watts) = 60.7 \cdot \text{jump height (cm)} + 45.3 \cdot \text{body mass (kg)} - 2055$$

Pull-ups were counted starting from a dead hang (arms are straight, and the body is unsupported). Hands face forward and are shoulder width apart. There is no kipping or assisting by movement of the lower body allowed and the chin must be raised above the bar for the pull-up to be counted.

Poundage pulled by the upper body was calculated by multiplying the subject's weight by the number of pull-ups completed.

Number 90^o push-ups were counted with cadence of 80 beats per minute. Subjects start with their chest on the ground and then perform push-ups to the cadence. The arms must fully extend at the end of the upward movement and elbows must bend to a 90^{o}degree angle prior to the subject pushing up again. Push ups are counted until the subject can no longer keep proper form within the cadence.

Plank time was considered the length of time a subject can hold a plank position. This position involves the subject having their elbows, forearms and toes on the ground while holding the rest of their body off the ground in a prone position. The body is to remain straight and once the subject can no longer hold the position; they are considered to have held the plank position to their maximum time.

VO_2max was measured in 2 different ways. Each participant has only one measure. Less than 10% of subjects had VO_{2max} directly measured. The mean scores between the shuttle run and direct measure did not vary so the values were combined in the analysis.

1. ***The 20m shuttle run*** (n=1044) test involves subjects running back and forth on a 20m course at various speeds ranging from 7-14km/hour. The pace is set with pre-recorded audio signals emitted at specific frequencies and subjects must complete the 20m run within the decreasing interval times. Subjects are instructed to

complete as many stages as possible and the test is stopped when the individual is no longer able to follow the pace. The last stage completed is recorded.

Prediction of VO_{2max} from the 20 m shuttle run stage completed using the Leger formula;

$$31.025 + (3.238 * shuttle\ run\ stage) - (3.248 * 18) + (0.1536 * shuttle\ run\ stage * 18)$$

2. ***Direct measure VO_2 max*** (N=51) was measured in L/min adjusted for body weight (ml/kg/min) by putting a face mask on the subject and directly measuring the volume and gas concentrations of inspired and expired air. The test involves either exercising on a treadmill or a bike at an intensity that increases every few minutes until exhaustion and is designed to achieve a maximal effort.

Appendix III

Alternative Analysis

Since males and females typically have different fitness scores (102) and injuries (103), it is important to examine the relationship between fitness test scores and musculoskeletal injuries (MSI) separately in order to avoid confounding and interactions due to sex. Age is an additional factor that can affect injury and fitness (102) so age will be controlled for in the analysis.

Descriptive Analysis

Participant data used in the analysis included data from 202 females (26 injured/176 uninjured) and 789 males (115 injured/674 uninjured). A sample size calculation indicated that 160 participants were sufficient to determine a medium effect size (0.15), power of 0.8 and a level of significance of 0.01 in a multiple regression analysis with 10 predictors.

Mean fitness scores between injured and uninjured subjects were examined and the student's ttest was used to determine if there was as statistically significant difference of the mean scores between injured and uninjured participants.

Mean scores

Females

The only fitness related variable that was statistically significant for females was body fat percentage ($p=0.04$). Injured females had significantly greater percentage of body fat (26.5%) when compared with uninjured females (22.4%)

Males

For males, several fitness scores differed significantly between injured and uninjured participants. Compared to uninjured males, injured males had significantly greater mass (kg), body fat (%), left grip strength (kg), right grip strength (kg), combined grip strength (kg), and leg power (Watts). Injured participants completed significantly fewer push ups and pull ups and had a lower maximal oxygen consumption (VO_{2max} (ml/kg/min)) compared to the uninjured participants.

Logistic Regression Analysis

Each of these steps would be done with the data for females and the data for males separately.

A matched case control analysis will be done to determine the relationship between fitness test scores and MSI. This will be done separately for males and females. Injured subjects will be matched with 2 uninjured subjects according to fitness test date (±30 days) to account for temporal variability in training protocols or work activity.

The dependent variable is dichotomous:

- Injured
- uninjured

All independent variables (fitness measures) are continuous and included:

- Age in years
- Body fat percentage
- Right grip strength (kg)
- Left grip strength (kg)
- Leg power (Watts)
- Number of pull ups
- Number of timed push ups
- Relative maximal oxygen consumption (VO_{2max} in ml/kg/min)
- Plank time (minutes)

Univariable Analysis

Univariable odds ratios (OR) and 95% confidence intervals (CI) will be estimated for each of the fitness measures in order to observe which are independently significant.

Multivariable Analysis

Age is a known confounder so will be forced into the model prior to purposeful selection being used to determine the main effect models. Interaction of age will be tested for each variable remaining in the model and then any significant interaction terms will be tested in the model to determine how the main effect changes. If the inclusion of an interaction term is found to improve the model, it will be included in the final model.

Table 1 – Mean scores females

	Not Injured					Injured					
Variable	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**p-value**
Age	168	34.79	5.94	22	46	26	36.85	5.9	25	47	0.11
Weight (lbs)	173	148.68	21.04	112.9	235.7	26	157.07	22.6	123.5	226.2	0.0859
Body Fat (%)	173	22.43	6.88	8.4	44.7	26	26.52	6.1	10.7	37.4	0.004
Right Grip (kg)	176	36.22	8.36	18	70	26	37.27	6.3	22	46	0.456
Left Grip (kg)	176	33.63	8.6	8	60	26	34.58	5.96	20	43	0.4817
Combined Grip (kg)	176	69.85	16.49	32	130	26	71.85	12.01	44	88	0.4584
Vertical Jump (inch)	170	100.82	4.57	90	118	26	99.44	3.87	91	108	0.1105
Leg Power (Watts)	168	3588.14	1177.45	452.52	16159.15	26	3621.58	569.34	2598.15	5132.68	0.8176
Number of Pull Ups	165	1.99	3.23	0	15	25	1.24	1.67	0	5	0.082
Amount pulled (kg)	166	128.07	213.31	0	1149.5	25	80.58	109.43	0	329.63	0.0925
Number Push-Ups	168	24.19	11.28	0	71	24	20.33	9.41	0	34	0.0785
VO_{2max} (mi/kg/min)	167	41.23	6.36	20.58	53.6	25	39.34	5.73	28.09	50.6	0.1409
Plank Time (minutes)	175	2.87	1.09	0.95	8.5	25	2.81	0.99	1.03	3.87	0.782

Table 2 – Mean scores males

	Not Injured					Injured					
Variable	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**N**	**Mean**	**Std Dev**	**Minimum**	**Maximum**	**P value**
Age	662	34.75	6.57	21	54	113	35.7	6.78	23	50	0.1695
Weight (lbs)	675	194.73	28.96	127.9	298.3	115	203.55	24.88	146.2	270.9	0.0008*
Body Fat (%)	671	19.33	6.34	4.6	42.9	115	21.05	5.95	7.4	36.1	0.0053
Right Grip (kg)	674	55.3	10.43	20	90	115	60.83	9.08	28	85	0.0001*
Left Grip (kg)	674	52.81	10.47	6	84	115	57.77	8.74	32	84	0.0001*
Combined Grip (kg)	674	108.11	20.14	32	170	115	118.6	17.1	60	169	0.0001*
Vertical Jump (inch)	673	112.19	5.93	54	177	114	112.79	5.04	96.5	128	0.2568
Leg Power (Watts)	670	5341.6	897.89	1069.23	16470.18	114	5482.13	657.26	3194.15	7300.65	0.0486*
Number of Pull Ups	657	8.42	5.54	0	31	115	7.16	5.58	0	21	0.0267*
Amount pulled (kg)	657	708.9	455.09	0	3366.61	115	636.48	486.16	0	1812.93	0.1394
Number Push-Ups	670	35.52	9.31	0	75	115	32.77	9.7	0	50	0.0055*
VO_{2max} (mi/kg/min)	644	45.01	6.25	20.58	62.6	113	43.55	5.34	29.59	54.9	0.0103*
Plank Time (minutes)	673	2.88	1.03	0	8.5	115	2.83	0.92	0	4.55	0.5896