2014

Physical fitness characteristics of an active firefighter population serving an urban area

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by

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Honours Bachelor of Science, University of Toronto, 2012

Thesis

Submitted to the Department of Kinesiology and Physical Education,

Faculty of Science, Wilfrid Laurier University

in partial fulfillment of the requirements for

Master of Science

Wilfrid Laurier University

June, 2014

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

– Michael R. Antolini

Abstract

Firefighters require a high level of physical fitness in order to meet the demands of their profession. While physical fitness testing is required to join the department, firefighters are not subject to further formal exercise testing throughout the duration of their careers. Active, career firefighters were tested on a variety of physical fitness measures related to body composition, strength, power, and endurance over three testing sessions. 49 firefighters (40.5 ± 8.3 yr, 89.5 ± 13.0 kg, 27.8 ± 3.6 kg/m^2) were found to have a resting heart rate of 57.7 ± 8.2 bpm, blood pressure of 121.5 ± 11.9/71.5 ± 9.9 mmHg, and 24.2 ± 5.4 % body fat, culminating in 7.6 ± 6.8 points in the CPAFLA Healthy Body Composition Score. They performed 31.4 ± 11.6 pushups and scored 15.6 ± 1.6 on the 21-point Functional Movement Screen. A subset of participants also completed the Wingate Anaerobic Test, producing 10.6 ± 1.1 W/kg at peak revolutions and averaging 7.4 ± 1.0 W/kg of power with a fatigue index of 49.7 ± 8.7% over the test duration. Maximum strength, as measured by torque produced in a 60°/s isotonic, concentric contraction was 3.0 ± 0.7 Nm/kg for the quadriceps and 1.0 ± 0.1 Nm/kg for the bicep. Measures of core torso strength included the 60° abdominal endurance test (153.8 ± 94.2 s) and Biering-Sorensen test (113.4 ± 48.6 s) for back extensor endurance. Vertical jump was found to be 50.0 ± 9.6 cm. VO$_2$ max was 42.2 ± 6.5 ml O$_2$/kg/min while VO$_2$ at the anaerobic threshold was 33.3 ± 8.2 ml O$_2$/kg/min. Many of the measurements taken displayed large ranges and though many firefighters performed above-average, there were a number who did not. The contrast between the highest and lowest performers for many measures suggests that there may be a small, but significant, portion of the population that do not possess the requisite fitness to optimally perform their job responsibilities. This is cause for concern and may be mitigated by implementation of mandatory

training and testing programs. Previous studies examining firefighter fitness have often used a young sample with little experience and fragmented testing while this report assessed greater numbers of senior firefighters and performed a more comprehensive range of testing. This is the first report of firefighter performance on Wingate tests, upper- and lower-body peak torque characteristics, and other performance and body composition characteristics. This data along with the other fitness measures assessed in this study will provide comprehensive baseline data to inform development of fitness training and maintenance protocols for active firefighters.

Acknowledgements

There are many people who have contributed to my thesis over the past two years that must be acknowledged. First and foremost, I must express my utmost gratitude for my supervisor, Dr. Peter Tiidus, for all of his guidance and expertise over the past two years. I am enormously grateful for his support and having had the opportunity to work with him. Thank you Peter for believing in me, your invaluable mentorship, and helping me to become a better student and researcher. I would like to also thank my committee members Dr. Jayne Kalmar and Zach Weston for their recommendations along the way and especially Zach for his knowledge and instruction in performing fitness testing. I must also acknowledge Angela Walzak for her technical support with much of the testing equipment. This study would not have been possible without the support and partnership of the Kitchener Fire Department and especially Steve Usher and Patrick O'Halloran for all their help with scheduling and recruitment efforts. I must also thank the firefighters of the Kitchener Fire Department who participated in my study, without them this would quite literally not have been possible.

Lastly, I would like to thank my family and partner for their unwavering support and encouragement. To my parents, Robert and Anne, and my brother Mark, thank you for your unconditional support and always believing in me. To my partner Melissa, thank you for all of your support, encouragement, and always being there for me the past two years anytime I needed anything at all, I could not have done it without you.

Thank you all who have helped me with this thesis project; it has been an extremely satisfying experience.

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List of Abbreviations and Definitions

ACSM – American College of Sports Medicine

ADP – Adenosine diphosphate

AMP – Adenosine monophosphate

ATP – Adenosine triphosphate

β-oxidation: Process by which free fatty acid molecules are broken down to produce acetyl-CoA

for entry to the Kreb's cycle

BMI – Body mass index

CPAFLA – Canadian Physical Activity, Fitness, and Lifestyle Appraisal

CPAT – Candidate Physical Ability Test

CPR – Cardiopulmonary resuscitation

CSEP – Canadian Society for Exercise Physiology

ECG - Electrocardiogram

$FADH_2$ – Flavin adenine dinucleotide

FFA – Free fatty acid

FMS – Functional Movement Screen

Glucose 6-P – Glucose 6-phospate

KFD – Kitchener Fire Department

Kreb's cycle: Metabolic pathway that transfers energy from carbohydrates, fats, and amino acids

to intermediate compounds for subsequent ATP production

METs – Metabolic Equivalent of Task: Physiological measure for expressing the energy

consumption of physical activities, set by convention to 3.5 ml O_2/kg/min

NADH – Nicotinamide adenine dinucleotide

NCAA – National Collegiate athletic Association

PAR-Q – Physical Activity Readiness Questionnaire

PCr – Phosphocreatine

P_i – Inorganic phosphate

PFK-1 – Phosphofructokinase-1

PFK-2 – Phosphofructokinase-2

RER – Respiratory Exchange Ratio: Ratio of carbon dioxide production to oxygen consumption, indicative of substrate utilization

V_E – Volume of air expired

Ventilatory Threshold: Inflection point at which pulmonary ventilation and carbon dioxide output begin to increase exponentially during exponentially increasing exercise intensity

VO_2 – Volume of oxygen consumed per minute

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1. Introduction

Firefighters are rescue workers extensively trained in dealing with fire suppression and prevention. In addition, they are often first-responders in a variety of medical emergencies and must be trained in both cardiopulmonary resuscitation (CPR) and first aid (1). Firefighting involves rescuing trapped victims, suppressing and controlling the spread of the fire, and limiting property and environmental damage. In addition, the personal safety of firefighters is of extreme importance when performing any task. It is extremely physically demanding and firefighters are often thought of as being very physically fit. While firefighters are most commonly associated with fire suppression, the reality is that it only generally accounts for about 1% of their total time on duty (2). A large portion of their time is spent educating the public about fire safety and prevention as well as being first responders to a number of different types of emergencies. Many duties that were traditionally associated with police officers, such as crime scene protection, are increasingly becoming the responsibility of firefighters as they often arrive at the scene first (1). Firefighters also regularly inspect buildings to ensure that they are up to fire-code and give fire prevention seminars in schools and at community events. Fire departments are usually optimized to serve either urban areas or rural/wild-land areas. Strategies for fire suppression and prevention as well as equipment used often differ between the two.

Unique occupational hazards manifest themselves in the firefighter population, mainly in the form of increased rates of cardiovascular incidents. Cardiovascular related deaths account for 45% of all firefighter deaths while on duty (2). This figure is much higher than the general average for cardiovascular death incidence of on-the-job deaths in the workplace, which is 15%, and also higher when compared to another public safety related work population, the police force

(22%). Kales et al. (2007) also found that 32% of deaths occurred during fire suppression activities even though it comprises the least amount of the typical work of firefighters by far (2). This represents an odds ratio of death of 136 compared to nonemergency duties. A possible cause of the increased rate of cardiovascular deaths during fire suppression may be due to the increased heart rates achieved as a result of the heat stress encountered by the firefighters (3). Firefighter recruits performed a cycle test to estimate maximum volume of oxygen consumed per minute (VO_2 max) before performing a simulated smoke-dive in full equipment (25 kg) in the heat to rescue a victim (70 kg mannequin) as part of their training. The 35 male recruits were found to have a VO_2 max of 52.4 ± 5.2 ml O_2/kg/min while their highest heart rate was 191 ± 8 bpm. During the smoke-dive, subjects averaged 60% of VO_2 max and 80% of heart rate max, but some subjects achieved heart rates greater than that of maximum achieved during the VO_2 max test. Two factors hypothesized to contribute to the increased heart rate are increased heat stress and the high use of upper body musculature (4). While the VO_2 max cycle test was performed at room temperature, during fire suppression the extreme heat encountered by firefighters necessitates that some blood be shuttled to the skin to dissipate heat. This results in an increased heart rate in order to maintain adequate blood flow to the muscles to perform the task at hand. In addition, perspiration decreases total body water and therefore blood volume. Stroke volume is then decreased so heart rate must increase in order to maintain cardiac output. This puts additional strain on the heart and therefore requires a greater blood supply to the heart itself. If the coronary arteries are narrowed from pre-existing medical conditions (e.g., increased blood lipids) or the heart can not maintain a sufficient cardiac output to supply oxygenated blood to both the peripheral muscles and itself, a myocardial infarction may occur (4). The second reason

is that during a rescue task there is significant work being performed by the upper body as opposed to just the lower body in a cycle test. The lower capillary volume in the upper body necessitates an increase in heart rate in order to maintain sufficient blood flow to overcome the increased flow resistance in order to fuel the muscles (4). Rodriguez-Marroyo and colleagues (2011) also identified increased psychological stress as a possible contributor to the higher heart rates seen during fire suppression (5). A group of sixty active male wild-land firefighters performed a treadmill VO_2 max test to determine three heart rate zones based around the ventilatory and respiratory compensation threshold. Subjects were found to have a maximal aerobic capacity (VO_2 max) of 54.2 ± 1.1 ml O_2/kg/min. Wearing heart rate monitors and using an intestinal temperature capsule, data was recording as firefighters performed either a direct attack (less than 5 m away from the fire, actively trying to suppress it) or an indirect attack (greater than 100 m away from the fire trying to control its spread) on the flames. Firefighters performing a direct attack had significantly higher heart rates and spent more time above the ventilatory and respiratory compensation thresholds than did those performing an indirect attack that spent more time below the ventilatory threshold. Interestingly, air and core temperature were not significantly different between the two attack types, ruling out cardiovascular drift as the cause of increased heart rate seen in direct attacks. It should be noted that fires requiring an indirect attack strategy are often larger and this may be the reason for the similarity in temperatures at different distances from the flames. The researchers hypothesized that increased psychological and emotional stress as a result of being so close to the fire was the cause of the increased heart rates seen in direct attacks. While there is a bit of a disconnect in the literature between the effects of heat stress on heart rate, it is clear that increased heart rates encountered

during fire suppression have a positive effect on cardiovascular incidents in this population of public safety workers.

In order to become a firefighter there is a thorough examination and interview process. In order to gain employment with the Toronto Fire Department, a department serving an urban area similar to that of the Kitchener Fire Department, potential candidates must first write an Aptitude Test which assesses their skills in memory and comprehension, understanding of firefighting material, mathematics, mechanical aptitude, and interpersonal relationships (1). After passing this examination, applicants must present a firefighting qualification (most commonly the National Fire Protection Association's Firefighter I & II Certification) before writing a General Firefighter Knowledge Examination. Candidates who possess a recognized certification (e.g., NFPA-1001) and have passed both exams (note that 70% is the minimum passing grade) are then placed in a hiring pool for interviews and a full medical examination including a vision, hearing, and acrophobia (i.e., fear of heights) test. In addition, successful applicants will have completed the Candidate Physical Ability Test (CPAT) in the previous six months. The CPAT is a pass or fail course that must be completed in 10 minutes 20 seconds or less and is administered by the University of Waterloo (6). Consisting of 8 different events that simulate different firefighter situations, participants must wear a 50 lb (22.7 kg) weighted vest to simulate the weight of equipment plus an additional 25 lb (11.3 kg) during the stair climb task to simulate a hose bundle. The events are, in order, a stair climb, hose drag, equipment carry, ladder raise and extension, forcible entry, search task, rescue task, and ceiling breach and pull. Hiring often takes place in cycles and is very competitive (1).

Firefighting is a very perilous profession that requires one to be in excellent physical fitness to pass the initial screening tests. They are at a greater risk of on-the-job cardiovascular incidents than the average job (2), with a major contributor to this increased risk being the heat stress encountered during fire suppression (3). Passing the CPAT to be eligible for hiring requires potential recruits to be very physically fit, and highlights the high fitness level required to be a firefighter.

Other than passing the CPAT in a specified time, for Kitchener and most other Canadian firefighter units, there are no specific physical fitness guidelines that need to be met once the firefighters secure employment and there are no continued requirements to demonstrate any specific fitness standards during employment though firefighting is by its very nature a physically demanding profession. Most of the research conducted on firefighters has focused on cardiovascular fitness, specifically on determining the oxygen consumption cost of firefighting and quantifying firefighters' VO_2 max. A lesser focus of research has been on determining the strength of firefighters as well as other anaerobic power measurements. One can argue that standardized fitness tests, more so than just the CPAT, are a necessity due to the high costs of training. A 2007 study by Lunt found that British Royal Navy recruits who took an optional pre-joining fitness test significantly improved their pass rates of training compared to those who did not, and had only about a third of voluntary releases (6% vs. 15%) (7). There was no requirement for applicants to pass the test, a 2.4 km timed treadmill run, it was only for participants' own knowledge of a general time required to succeed in training. Having additional benchmarks for applicants to strive for before applying can only help the process and reduce time and money wasted on incomplete training.

A brief review of the current literature on exercise physiology and firefighter fitness is needed before delving further into ways of characterizing the fitness and health status of veteran firefighters who have been employed for a significant period of time. In particular, there is less information on the conditioning levels of veteran firefighters than on new recruits. Although firefighters are encouraged to exercise regularly and to maintain fitness, and are often provided with opportunities to train, little is currently known about the degree to which veteran firefighters avail themselves to these opportunities and what the overall fitness status is of firefighters who have been working for a number of years.

When a group of active firefighters was asked to report their fitness level on a scale from 0-7, no association was found between their perceived level of fitness and actual fitness as determined by a treadmill VO_2 max test (8). This would highlight the need for comprehensive fitness testing in order to better establish the fitness level of current firefighters as well as their perceptions and understanding of their actual fitness levels and limits. This information may be especially pertinent to older, veteran firefighters as they are at a higher risk for cardiovascular incidents than younger firefighters are (OR: 4.4; 95% CI: 1.7 – 11.1) (9).

Briefly stated, the current study aimed to create a Canadian database of firefighter physical fitness characteristics, create a testing battery that is predictive of work performance and injury risk, and make recommendations regarding the composition of physical fitness training programs tailored for active firefighters.

1.1 Energy Systems

Adenosine triphosphate (ATP) is the primary molecular compound that the body uses for energy, in the form of chemical energy within its phosphate bonds (10). The enzyme ATPase is

able to cleave off one of the phosphate groups to liberate the chemical energy stored within its bond for various processes within the body. Adenosine diphosphate (ADP) is a relatively low energy molecule that can be converted back to ATP through the process of phosphorylation by way of either aerobic or anaerobic metabolism. The body is unable to store large amounts of ATP (only about 80-100 g, enough for a few seconds of activity) so it must continually be synthesized by either the phosphocreatine, glycolytic, or oxidative systems (11). In addition to being unstable due to its high-energy phosphate bonds, ATP is also quite heavy, such that the average sedentary person is estimated to resynthesize an amount of ATP every day equal to about 75% of their body weight (11).

The body is able to resynthesize ATP most rapidly using the anaerobic phosphocreatine system (10). Creatine is a nitrogenous organic acid that is able to bind to an inorganic phosphate (P_i) to produce phosphocreatine (PCr), of which the body is able to store four to six times the amount of ATP (11). In times of increased energy demand, the enzyme creatine kinase is able to cleave P_i from PCr and the energy produced allows for the reformation of ATP from ADP and P_i. This process occurs quite rapidly and does not require the presence of oxygen, but is only able to sustain ATP levels for about 10 seconds before exhaustion of PCr stores. Creatine kinase is also able to reform PCr from creatine and ATP during rest in order to replenish the phosphocreatine system for the next bout of intense physical activity.

For activities lasting longer than a few seconds, the glycolytic system is able to anaerobically produce ATP for approximately two minutes of activity (10). Glycolysis, or the breakdown of glucose, requires that 2 ATP be consumed initially but produces 4 ATP (net 2 ATP) and 2 NADH (nicotinamide adenine dinucleotide, a reducing agent for aerobic metabolism) for

every molecule of glucose. Liver or muscle glycogen can also be used in this process and actually results in a net of 3 ATP being produced, as it is able to bypass an initial step in glycolysis (11). In the absence of oxygen, the final product of glycolysis, pyruvate, is converted to lactate. This occurs because glycolysis requires NAD^+ in one of its steps but if oxygen is not available, NADH cannot be oxidized so pyruvate accepts its protons to become lactate. Due to this, the phosphocreatine and anaerobic glycolytic system are only able to generate ATP for intense physical activity for short durations in comparison to the slower but much more efficient oxidative system, capable of maintaining ATP production for hours.

The oxidative system is the most complex of the three energy systems but is capable of producing the most energy by using oxygen to assist in metabolizing fuel sources in the process of cellular respiration (10). The previously discussed glycolytic system produces 2 pyruvate, but in the presence of oxygen these will be converted into acetyl coenzyme A (acetyl CoA), which is able to enter the Krebs cycle, also known as the citric acid cycle, in addition to forming 1 NADH. The Krebs cycle produces 1 ATP as well as 3 NADH and 1 $FADH_2$ (flavin adenine dinucleotide) to act as reducing agents per acetyl CoA that enters. The final process of aerobic metabolism is the electron transport chain in the mitochondria where hydrogen atoms carried by the coenzymes NADH and $FADH_2$ are split into electrons and protons to provide the energy needed to phosphorylate ADP, forming ATP. This process is able to produce 36-39 ATP per molecule of glucose that begins aerobic glycolysis but is slower than anaerobic metabolism and cannot match the energy needed during high-intensity activity. The difference in ATP production is due to whether glucose comes from the blood stream or glycogen and whether NADH or $FADH_2$ is used to transport electrons through the mitochondrial membrane to the electron

transport chain. If electrons are originally donated by NADH, 3 ATP are able to be produced but if donated by $FADH_2$ only 2 ATP can be produced because it enters the electron transport chain at a lower energy level, bypassing the first site of ATP synthesis (11).

Oxidation of fat is very similar to aerobic metabolism of glucose. Fat for energy production is stored in the body as triglycerides that must be broken down into glycerol and three free fatty acids (FFAs), in the process of lipolysis, in order to be oxidized for ATP production (10). Though FFAs can be of different lengths and structurally different, they are all cleaved into 2-carbon units of acetyl CoA through the process of β-oxidation. From this point onwards, fat metabolism follows the same pathway as carbohydrate metabolism with acetyl CoA going through the Krebs cycle and then the electron transport chain. Glycerol cleaved from triglycerides is also metabolized, degrading to pyruvate and then entering the Krebs cycle, just as a pyruvate formed from glycolysis would (11). ATP production is dependent upon the length of the FFA being oxidized and specifically the amount of acetyl CoA molecules it is able to produce. For example, a 16-carbon FFA such as palmitic acid is able to produce 129 ATP when fully oxidized. Though fat is able to provide more energy per gram (9.4 kcal/g) compared to carbohydrate (4.1 kcal/g) it requires more oxygen (5.6 ATP/O_2 compared to 6.3 ATP/O_2 for carbohydrate). During high-intensity activity oxygen transport is often the limiting factor in performance so carbohydrate is the preferred fuel. In addition to aerobic metabolism being slower than anaerobic metabolism, lipid oxidation is slower than carbohydrate oxidation, explaining why an athlete's intensity level will decrease when carbohydrate stores become depleted and fat becomes the predominant fuel source.

It is worth noting that protein can also be used as a fuel source in the form of amino acids. Some amino acids are able to be converted into glucose in the process of gluconeogenesis as well as intermediate products in aerobic metabolism such as pyruvate and acetyl CoA (10). However, since protein metabolism accounts for less than 5% of total energy expenditure during either rest or exercise, it is usually excluded in energy expenditure estimates.

1.2 Aerobic Fitness

Aerobic capacity refers to the maximum amount of oxygen one is able to uptake during exercise, also known as VO_2 max. Although controversial, maximum oxygen uptake is often thought to be limited by the capacity of the cardiovascular system to deliver oxygen to the working muscles (4). Regarded as the best measurement of cardiorespiratory endurance and overall aerobic fitness, VO_2 max tests can be performed in a number of ways (10). Direct measurement via gas exchange is more accurate than estimating VO_2 max using indirect methods, such as extrapolating heart rate and workload to a theoretical max. In addition, as long as safety allows for it, maximum effort tests are more accurate than using a submaximal test in which extrapolation must be used to estimate VO_2 max. With training it is possible to increase one's VO_2 max but it has been demonstrated that it will eventually plateau. Training adaptations which influence VO_2 max include increased blood and hematocrit volume, left ventricle size, cardiac output, and peripheral capillarization which augments local blood flow and enhances arterial-venous O_2 difference, or local oxygen uptake (4). Continued training will allow one to sustain work at a greater percentage of VO_2 max, which translates into athletic and submaximal exercise performance gains. This is often measured as the percentage of VO_2 max that corresponds to a non-linear increase in blood lactate accumulation ("anaerobic threshold") and/or

a non-linear increase in ventilation ("ventilatory threshold"). Training adaptations that facilitate improvements in the anaerobic or ventilatory threshold include increased muscle mitochondria, which facilitate greater fat utilization, a relative reduction in carbohydrate utilization, and a reduction in glycolytic flux at any given workload (4).

Submaximal athletic or work performance is better predicted by the anaerobic, or ventilatory, threshold rather than VO_2 max. The anaerobic threshold is the intensity at which lactate begins to quickly accumulate in the blood and the body begins shifting towards anaerobic metabolism, as aerobic metabolism cannot continue to meet energy demands and glycolysis rate begins to exceed the rate of aerobic metabolism. At this point the body is no longer in steady state and will not be able to sustain the heightened intensity level for long (12). However, most reasonably fit individuals can sustain work for a significant period of time at intensities at or just below the ventilatory threshold. Thus the work capacity at the ventilatory threshold is a good measure of the maximal energy expenditure or functional capacity that can be carried on for a significant period of time (4).

Exercise intensity is sometimes classified in terms of metabolic equivalents (METs) since the amount of oxygen consumed by the body is directly proportional to the energy requirements of an activity (10). At rest the body requires approximately 3.5 ml O_2/kg/min for basic metabolic functioning and this is defined as 1.0 MET. Different activities then can have their oxygen requirement classified by METs, which may be easier to use for the purposes of prescribing exercise. Walking at a speed of 4 km/h for example, requires approximately 10.5 ml O_2/kg/min, so it would be equivalent to 3.0 METs.

Early research regarding firefighters first focused on determining the metabolic cost of firefighting in terms of oxygen consumption. VO_2 max was determined in a group of 17 firefighters using a graded maximal cycle test and then, to simulate a firefighting task, subjects performed a stair climb wearing full equipment weighing an additional 86.5 lb (39.2 kg) for five minutes (13). Results indicated that heart rates reached 95% of maximum, with an oxygen cost of 39 ml O_2/kg/min, corresponding to 80% VO_2 max during this task. Researchers found the range of fitness levels of subjects most alarming, even with such a small sample size. Subjects achieved oxygen consumption values ranging from 63% to 97% of VO_2 max to complete the stair-climbing task, leaving very little margin of reserve fitness for an unexpected increase in workload in many of the subjects. Considering the effects of heat stress (3) this becomes even more alarming. O'Connell et al. (1986) conclude that a VO_2 max of 42 ml O_2/kg/min should be a sufficient fitness level to meet the demands of firefighting, but recommend that firefighters be able to consume 49 ml O_2/kg/min to provide a margin for safety (13). Rather than use a task that simulates energy demands a firefighter might encounter, Sothmann et al. (1992) had a group of 10 firefighters wear heart rate monitors during actual fire suppression emergencies (14). Later, the same group performed a treadmill VO_2 max test and the researchers used heart rate values to estimate oxygen consumption while engaged in fire suppression. As previously discussed (3,5), heart rate is increased during fire suppression above actual VO_2 requirements due to factors such as heat stress, upper body activity, and psychological stress. Taking this into account and applying a statistical correction, researchers estimated that the average cost of firefighting was 33.1 ml O_2/kg/min (14). This value is consistent with previous literature in the area suggesting that the average short-term energy cost of firefighting is 35 ml O_2/kg/min (13,15). Adding a 20%

buffer for safety, a VO$_2$ max of 42 ml O$_2$/kg/min has been recommended as a minimum for firefighters to ensure that there is an adequate reserve capacity for cardiovascular stressors (14).

Cardiorespiratory fitness can be used as general measure of health and subsequent injury risk (15). Prior to 2004, all firefighter recruits in the United Kingdom underwent a formal assessment of cardiorespiratory fitness and had to have a VO$_2$ max of at least 45 ml O$_2$/kg/min to be admitted into training. In light of mounting evidence that firefighting requires 35 ml O$_2$/kg/min (13,14) plus a 20% safety buffer, the cardiorespiratory standard was amended to 42 ml O$_2$/kg/min in 2004. After this change, some fire departments adopted the new standard of 42 ml O$_2$/kg/min and some kept the old standard of 45 ml O$_2$/kg/min, while others dropped the cardiorespiratory standard requirement altogether from the application process. After following new recruits for 4 years it was found that when controlling for age and gender, eliminating the cardiorespiratory standard increased injuries by 8%, however there was no statistically significant difference in injury rates when a cardiorespiratory standard was maintained, be it 42 or 45 ml O$_2$/kg/min (15). It may be that having a fitness standard eliminates some candidates who are at the lower end of the physical fitness spectrum to begin with and this is driving the lower injury rates seen after four years of follow-up.

An inverse dose-response relationship was found between cardiorespiratory fitness and physiological abnormalities following an exercise stress test (16). Firefighters performed a VO$_2$ max treadmill test and were tested for abnormalities in maximum heart rate achieved (< 90% age-predicted maximum), heart rate recovery at one minute post-test (< 12 bpm decrease), blood pressure response (> 220/90 mmHg), and electrocardiogram (ECG) reading (ST segment elevation or depression > 0.5 mm). Participants were divided into quartiles based on VO$_2$ max

and it was found that 64% of subjects in the lowest quartile experienced at least one post-test abnormality while only 23% of the most fit subjects experienced one symptom.

A cross-sectional study of 968 male career firefighters aimed to further quantify the relationship between cardiorespiratory fitness and cardiovascular disease risk factors (17). Higher VO_2 max values had an inverse association with diastolic blood pressure, body fat, triglycerides and low-density lipoprotein (LDL) cholesterol. In addition, higher cardiorespiratory fitness was also associated with higher high-density lipoprotein (HDL) cholesterol. All relationships remained significant after adjustment for age and body mass index (BMI). Less than half of the participants tested met the 42 ml O_2/kg/min standard and almost 90% were classified as overweight or obese by BMI standards. Though BMI has been criticized for not taking abnormally large lean body mass into account, blood markers of cardiovascular risk factors and body fat percentage have been positively correlated with increased BMI in this population (17).

Various studies have looked at the cardiorespiratory fitness of firefighters in an attempt to accurately describe the population. In most active veteran firefighter populations tested the average is well below the aerobic power standard of 42 ml O_2/kg/min for firefighting. In 1998, Campbell et al. performed a fitness assessment of 65 active firefighters serving an urban area and found their VO_2 max to be 33.7 ml O_2/kg/min (18). In addition, not a single firefighter assessed performed at or above the recommended minimum standard for all tests (included a variety of strength and anthropometric measures also). Baur et al. (2012) categorized their subject pool of 1149 male career firefighters according to metabolic equivalents (METs) and 1 MET is equal to 3.5 ml O_2/kg/min so 12 METs would be considered the aerobic power standard (12 x 3.5 = 42 ml

O$_2$/kg/min) (16). Unfortunately, actual VO$_2$ max values were not given as participants were divided into categories based on METS, but 589 or 51.3% of subjects fell below the 12 MET standard. A smaller study performed on 10 career male firefighters provided a VO$_2$ max of 40.0 ± 6.4 ml O$_2$/kg/min from a treadmill test (14). Using a mixture of both urban- and suburban-serving male career firefighters, another study found cardiorespiratory fitness to average 12 METS, although there was a considerable range in the results, from less than 10 METS to greater than 14 METS (17). Calavalle et al. (2013) assessed VO$_2$ max in male career firefighters as part of a larger study to determine what variables can be measured to predict cardiorespiratory fitness (19). Their sample of firefighters was able to consume 39.6 ± 6.1ml O$_2$/kg/min, as estimated by a submaximal graded treadmill exercise test.

In a study using 35 male firefighter recruits as subjects, a VO$_2$ max of 52.4 ± 5.2 ml O$_2$/kg/min was observed (3). Rodriguez-Marroyo et al. (2011) found that male wild-land firefighters with two years of experience were able to maximally consume 54.2 ± 1.1 ml O$_2$/kg/min (5). From these studies it appears that while longer serving career firefighters do not generally meet the minimum recommended fitness standard for aerobic power, younger, more recent recruits do. The two studies that resulted in favourable fitness outcomes (3,5) used new recruits and firefighters with only two years of experience and it can be argued that using these younger firefighters does not represent an accurate sample of firefighters as a whole. Recruits often have excellent fitness as they must pass a fitness test to get into the training program. Those who have only two years of experience are likely to be young and still exercising quite regularly. However when the population is looked at as a whole with varying years of experience and age, it can be

seen that the cumulative cardiorespiratory fitness decreases (14,16,18,19) and this is of some concern.

When firefighters are compared to other populations with some similar work demands and stresses, their cardiorespiratory fitness levels still tend to be lower. Police officers of varying seniority from new recruits to the Chief of Police were tested and found to have an average VO_2 max of 44.3 ± 5.8 ml O_2/kg/min (20), which is above the 12 MET (42 ml O_2/kg/min) standard for firefighters. Pryor and colleagues (2012) performed fitness testing on Special Weapons and Tactics (SWAT) officers and found them to possess good cardiorespiratory fitness, at 45.3 ± 6.1 ml O_2/kg/min (21). Aerobic power of untrained undergraduate and graduate university students was 41.7 ml O_2/kg/min for males and 35.4 ml O_2/kg/min or females (22). Normative population data in 2012 from the American College of Sports Medicine (ACSM) for 20-29 year olds at the 50th percentile for VO_2 max is 42.5 ml O_2/kg/min for males and 35.2 ml O_2/kg/min for females (23), very similar to values found by Bulbulian et al. (1996) more than 15 years prior (22). Males aged 30-39 typically average 41.0 ml O_2/kg/min while females average 33.8 ml O_2/kg/min. VO_2 max values continue to decrease as age progresses with 40-49 year old males and females averaging 38.1 and 30.9 ml O_2/kg/min, respectively (23). Looking at these comparisons, it appears that firefighters are not as aerobically fit as we would expect them to be. SWAT officers wear about 50 kg of gear and equipment (21), approximately double that of firefighters, so this may be the reason the group tested has higher cardiorespiratory fitness as they carry more weight during their daily activities. However, it could be argued that all firefighters, regardless of age or length of service, should have at least comparable cardiorespiratory to regular police officers and university students who are at or above aerobic power levels recommended for firefighters when

one considers that a significant portion of their job responsibilities is rescuing people from burning buildings.

1.3 Anaerobic Power and Muscular Strength

As previously discussed, short-duration, high-intensity events utilize ATP very rapidly and hence require a very rapid rate of ATP resynthesis, such that aerobic metabolism is not sufficient. In these instances, anaerobic metabolism by way of the phosphocreatine and glycolytic systems generate an increasing amount of ATP to sustain muscle contraction. Anaerobic power reflects the maximal energy output of these systems and is of great importance in sport, particularly events where high muscular force must be produced quickly and only sustained for a short period of time, such as sprinting.

Anaerobic glycolytic capacity is controlled by concentrations of various enzymes and their substrates. Often these regulatory enzymes catalyze irreversible reactions near the beginning of a pathway and in the case of glycolysis, hexokinase and phosphofructokinase-1 (PFK-1) act in this capacity (12). When glucose first enters the cell via GLUT-4 transporters it is phosphorylated by hexokinase to glucose 6-phosphate (glucose 6-P) in one of the priming (energy-input) steps of glycolysis. If glucose 6-P concentration increases due a slow-down at another step or an increase in glycogen breakdown (glycogen is broken down directly into glucose 6-P, bypassing hexokinase) then it will slow down the rate of reaction for hexokinase via negative feedback. PFK-1 is the main regulatory enzyme of glycolysis as it commits the sugar molecule for degradation by phosphorylating fructose 6-P to fructose 1,6-bisphosphate. A number of substrates act as modulators of PFK-1 activity, including ADP, AMP, and P_i. Increased concentrations of these products indicate a high rate of ATP utilization and hence act as allosteric

activators to increase PFK-1 activity and therefore increase substrate availability (fructose 1,6-bisphosphate) for glycolysis. PFK-1 activity can also be allosterically increased by fructose 2,6-bisphosphate formed by phosphofructokinase-2 (PFK-2). PFK-2 activity is increased by epinephrine and muscle contraction, both of which are increased during exercise or times of increased ATP demand, in order to increase ATP production via glycolysis by increasing PFK-1 activity to make more substrate available.

Buffers resist pH change by either bonding to H^+ ions when a solution becomes more acidic or releasing protons to make a solution more acidic when it is becoming alkaline. They play an important role in allowing the glycolytic pathway to continue producing ATP as H^+ ion accumulation occurs during the upregulation of anaerobic metabolism. Bicarbonate is the most important buffer in the body as it combines with a proton to form carbonic acid which then dissociates to water and carbon dioxide which can be exhaled (4). Intracellular buffers in muscle fibers include proteins, which can accept protons on their amine or carboxylic acid group, phosphate groups (including phosphocreatine), and bicarbonate. Muscle buffering capacity is limited and intense exercise can decrease muscle pH quite a bit so extracellular buffers in the blood also exist as pH regulation in blood is much more restricted. Proteins, bicarbonate, and hemoglobin all contribute to blood buffering and interestingly, deoxygenated hemoglobin has a greater buffering capacity than oxygenated hemoglobin so it is better able to accept protons from working muscles after it has shuttled oxygen there which also helps to reduce acidity by allowing the electron transport chain to operate and use some hydrogen ions.

Exercise training can improve anaerobic power by improving the phosphocreatine and glycolytic systems' ability to generate ATP as well as buffering capacity and acid-base control.

The phosphocreatine and glycolytic systems can be improved by training them in the manner that they are used. That is, short high-intensity bouts of exercise interspersed with recovery periods. This is known as high-intensity interval training and has been shown to increase glycolytic enzyme concentration and creatine kinase reaction speed so that faster ATP turnover is possible (4). Interval training also has the added benefit of slightly improving aerobic power and mitochondria concentration in muscle, which helps to create additional ATP to spare PCr. Intracellular muscular buffering capacity is also increased with high-intensity training (24).

Muscle fibers can be categorized as either slow-twitch (type I) or fast-twitch (type IIa and IIx) based on how quickly they can reach peak tension (10). The rate of skeletal muscle fiber contraction is determined by the rate of myosin head ATPase activity as different types of myosin heads exist. The rate at which myosin can hydrolyze ATP determines the rate of cross-bridge formation and cycling, which in turn determines the maximal contraction velocity of the fiber. Type I fibers may also be called slow oxidative fibers because they have a high resistance to fatigue and oxidative capacity but are unable to contract quickly or produce a large amount of force. On the contrary, type IIx fibers are also known as fast glycolytic fibers and fatigue quite quickly due to a low oxidative capacity but are able to produce a tremendous amount of force very quickly. Type IIa fibers, or fast oxidative glycolytic fibers, lie in the middle of the spectrum of the fiber types but have characteristics closer to type IIx, hence their classification as fast-twitch.

A motor unit consists of a single motor neuron and all of the muscle fibers that it innervates (10). Muscle fibers are recruited according to the size principle, such that motor units are recruited in order of increasing motor neuron size as effort increases. Since slow-twitch

motor units are innervated by smaller motor neurons, these fibers are recruited initially for force production. As force requirement and effort increases, motor units of type IIa fibers will be additionally recruited and finally at near-maximum effort type IIx motor units will be additionally recruited to maximize force production. Note that at maximum effort type I and IIa motor units continue to contract and produce force. As with energy systems, muscle fiber recruitment operates on a continuum rather than an absolute on-off system of the different fiber types.

Many factors come together to determine the maximum force a contracting muscle is able to generate. Most obviously, larger muscles are able to produce a greater force as there are more actin and myosin filaments able to form cross-bridges and initiate contraction. As previously discussed, type IIx fibers are able to produce the most force and with the greatest shortening velocity because calcium is released from the sarcoplasmic reticulum at the fastest rate to allow cross-bridges to form and they also have higher ATPase activity (4). Muscle length at the time of contraction is also an important factor in force production as there exists an optimal length and subsequent overlap of actin and myosin filaments that allows for maximal cross-bridge formation and therefore, tension development (4). Too little or too much overlap limits cross-bridge formation simply due to availability of binding sites and fewer bound myosin heads means less power strokes and therefore less force production.

Exercise training can increase muscular force production through both neural and physiological means. Rapid strength gains at the start of a resistance training program are mainly due to neural adaptations and not changes in muscle size (4). Resistance training only one arm has been shown to exhibit a "carry-over" effect whereby the untrained arm experiences strength

gains as well even without the training stimulus or hypertrophy (25). This demonstrates the concept of neural learning, resulting in improved coordination and ability to recruit motor units synchronously for improved force production. Physiologically, skeletal muscle responds to strength training by increasing in size. Hyperplasia is an increase in total number of muscle fibers while hypertrophy refers to an increase in individual fiber size or cross-sectional area (4). Though hyperplasia has been demonstrated in animals, it is not clear if it occurs in humans and even if it does, it contributes very little to increases in muscle size. Hypertrophy occurs via undifferentiated satellite cells fusing with existing and damaged (from training) muscle fibers and donating their nucleus to the fiber. Muscle fibers are multinucleated cells but maintain a certain nucleus to cytoplasm volume, termed the myonuclear domain (26). This is necessary because a nucleus can only sustain gene expression and subsequently, protein synthesis, for a limited cytoplasm volume so in order to increase in size additional nuclei are needed. Resistance-training induced increases in muscle fiber size (hypertrophy) increases actin and myosin filaments due to the addition of sarcomeres in parallel (4). This creates more opportunities and sites available for cross-bridge formation, thus increasing the fiber's ability to generate force.

Anaerobic power and muscular strength are other important components of a firefighter's overall physical fitness. The Wingate test, which involves a 30-second maximal effort cycling bout against a heavy resistance (usually 7.5% of body weight), is commonly used to assess anaerobic, or glycolytic, capacity and lower body power (27). Female firefighting recruits from the Chicago area were assessed using a variety of strength and power tests as well as anthropometric measures (28). Researchers were attempting to link performance in the stair-climbing task as part of the application process to a standard fitness measure. The recruits

averaged 398.2 ± 56.9 W in the Wingate test with a peak power of 494 ± 84.7 W. Vertical jump height for the group was measured at 31.0 ± 4.8 cm while leg press averaged 143.5 ± 30.3 kg. When compared to normative data, Misner et al. (1988) found that the female recruits generally score better than reference adult women, but poorer than reference adult men (28). In addition, the stair-climbing test, which is used to assess leg power in the field, was only slightly correlated with any tests of anaerobic leg power. Interestingly, the best predictor of performance on any test was lean mass. Michaelides et al. (2008) performed a similar study to the aforementioned one but instead used male firefighting recruits (29). They attempted to link muscular strength and body composition to performance in the Arkansas Ability Test (similar to the CPAT required for firefighters in Toronto and Kitchener). Average body fat for the male recruits was $21.8 \pm 6.2\%$ while maximum bench press, as a measure of upper body strength, was 96.1 ± 22 kg. Upper body muscular endurance was tested via pushups and averaged 35.6 ± 15.3 repetitions. Somewhat opposed to the previous study utilizing female firefighter recruits (28), assessments of upper body muscular strength and endurance best correlated with ability test time for males (29). In a study of 20 career firefighters, correlations were found between simulated job performance tasks and various fitness measurements (30). Highest and most frequent correlations were found with 400 m run time, a test of anaerobic power/endurance. This may be because many firefighting tasks operate within the same time range as a 400 m run. Interestingly, body composition and cardiorespiratory fitness did not correlate greatly with many performance variables. This may be because full recovery was allowed between performance tasks in order to rule out the effects of fatigue. Had this not occurred, VO_2 max values would probably have had higher correlations. A fitness assessment of career firefighters performed by Campbell et al.

(1998) revealed that average one-repetition maximum for bicep curl was 46.4 ± 11 kg and that over 65% of participants fell below the 120 lb (54.5kg) standard for firefighting (18). Leg dynamometry (measuring the force production by holding a handle while attempting to stand upright on a platform) tested at 152.2 ± 36.7 kg but 45% of firefighters fell below the ACSM average for leg strength. In addition, the group averaged 21.3% body fat, which is higher than recommended for optimal health.

As with cardiorespiratory fitness, when comparing firefighters' muscular strength to other population groups the results are discomforting. Active SWAT officers are able to leg press 243.4 ± 32.7 kg, which ranks in the 90th percentile for age- and gender-based normative data, bench press 105.6 ± 16.2 kg (85th percentile), and jump 41.8 ± 5.3 cm (50th percentile) (21). Regular police officers have 17.7 ± 4.5% body fat according to Stamford et al. (1978) (20). They also found that the physical fitness of police officers declines with age and length of service, eventually reaching a level below what would be expected of a professional working in the public safety sector. This demonstrates that the physical rigours of police work alone are not sufficient to maintain the necessary fitness level and highlights the need for continuous training to counteract the age-related decline in fitness. It would therefore not be difficult to imagine that firefighting would pose a similar situation.

Murphy et al. (1984) found that about 50% of the variance in anaerobic power capacity can be attributed to thigh volume, body weight, and lean mass (31). Males in their study performed a Wingate test with an average of 555.4 W while females' power averaged 334.3 W. Peak power was 750.4 W and 503 W for males and females, respectively. Maximum power achieved during the Wingate test for male intercollegiate (NCAA) athletes was 11.65 W/kg while

female athletes peaked at 9.59 W/kg, according to a 2009 study (32). In addition the authors add that studies using a Wingate test performed on Monark bikes prior to 1999 often underestimate peak power because the weight was not loaded instantly in those older models of cycle ergometers. The implication of this is that some of the previously discussed studies for comparison, which put firefighters in a negative light in terms of anaerobic power, may not actually be as bad as believed.

Normative population data at the 50th percentile for 20-29 year olds from the ACSM lists pushups at 28 repetitions for males and 20 for females (23). Bench press is listed at 1.06 times body weight for males and 0.4 of body weight for females while leg press should be 1.91 and 1.32 times body weight for males and females, respectively.

1.4 Validity and Reliability of Measurements Performed

In addition to the types of measures previously reported on firefighters, the present study performed a number of other measures, some of which have not previously been reported with a firefighter population.

Many of the techniques used in this study have been previously shown to be both valid and reliable. Validity refers to the ability of a measurement to actually measure what it intends to measure; for example, a questionnaire designed to measure one's self-esteem would have high validity if it actually measures self-esteem levels and not extroversion. Reliability is the ability of a measurement to produce relatively similar results when repeated. A scale used to measure body weight with high reliability should produce the same result if a person steps off the scale and then back on again without any change in their physical condition.

The Canadian Society for Exercise Physiology (CSEP) maintains a screening form for those wishing to become physically active, entitled the Physical Activity Readiness Questionnaire (PAR-Q) (33). Originally developed by Chisholm et al. (1975), the PAR-Q aims to identify people for whom beginning a physical activity program may be detrimental based on pre-existing health conditions (34). It was originally designed to be conservative in order to minimize risks (35) and this is reflected in the exclusion rates it produces (~35%), some of which are false positives (36).

Measurement of skinfold thickness for the purpose of determining body fat percentage is an attractive option due to its quickness, low-cost, and ease of use. Measuring a skinfold's thickness gives an indication of the amount of subcutaneous fat at a particular site (37). These measurements can then be used to calculate body density and eventually body fat percentage. Equations used in these calculations are based on numerous studies that have tested many people for skinfold thickness and also using other accurate methods of determining body fat percentage, such as underwater (hydrostatic) weighing, and then linking the two together. There are many different sites at which skinfold thickness can be measured and different equations for calculating body density depending on the sites chosen. Skinfold thickness measurements have been shown to be both reliable and valid when compared to using hydrostatic weighing to calculate body density and then body fat percentage from this (38). Cross-validation correlation coefficients between skinfold measurements and hydrostatically determined body fat percentage was shown to be $r = 0.92$ for males and $r = 0.88$ for females ($p < 0.001$). Skinfold thickness measurements were also shown to be reliable with 97.7% and 98.8% of the variance in measurements of males and females, respectively, being attributed to differences in subjects and

the standard error of measurement being 1% and 0.9% body fat in males and females, respectively. As previously noted, there have been a limited number of studies that have provided body composition data on active firefighters.

The Functional Movement Screen (FMS) is a tool used to identify functional movement compensations due to underlying muscle imbalances and has been used to predict general risk of musculoskeletal conditions and injuries (39). Seven movements are performed to give a composite score ranging from 0-21 points and a composite score less than or equal to 14 has previously been indicated to have an increased injury risk in professional American football players (40). Although scoring of the various movements is subjective, there are a set of criteria for each movement outlining common compensations and things to look for. The FMS has been shown to be reliable with the inter-rater correlation coefficient being 0.76 (95% CI: 0.63, 0.85) and test-rest reliability coefficient slightly lower at 0.74 (95% CI: 0.6, 0.83) (39). Previous research has also linked composite FMS score to injury in firefighters, as the odds of scoring 16 or lower were 1.68 times greater (p = 0.033) for those with a history of any injury (41). In addition, new recruits in the firefighter academy who became injured over the duration of their training had lower pre-training composite FMS scores (13.8 ± 2.3 vs. 14.9 ± 1.7, p = 0.01) than those who did not (42).

The American College of Sports Medicine (ACSM) Pushup Test (43) was used to assess muscular endurance of the upper-body musculature, particularly the triceps, anterior deltoids, and pectoral muscles although many other muscle groups in the upper-body are used for support and stabilization. More specifically, this test attempts to quantify absolute muscular endurance by

measuring the total number of repetitions performed at a given resistance. As previously noted, there is only limited data on firefighter populations using this type of measure (29).

The current gold standard for assessing intermediate-term anaerobic power is the 30-second Wingate Anaerobic Test, first described in 1974 (44). It was originally conceived as a test of lower-body and leg power but has since been adapted so that the same principles can be used to assess upper-body and arm anaerobic power (27). The Wingate test provides data on the subject's peak power produced over a 5-second interval, mean power produced over the entire 30-second test, and fatigue index, the difference between the peak and minimum power produced. Generally thought of as a reliable instrument, test-retest reliability coefficients of peak and mean power range from 0.9 to 0.98, though the fatigue index (r = 0.43) is considerably less reliable (27,45).

Many muscles within the torso are required for stabilization of the spine and isometric endurance times in various postures can provide insight into the fitness of these muscle groups, specifically the quadratus lumborum (46). While the abdominal muscles also provide stabilization to the spine, the quadratus lumborum was the most active muscle during any upright posture. The flexor endurance test (47), also known as the 60° abdominal muscle endurance test, coupled with the extensor endurance, or Biering-Sorensen test (48) are used to provide a measure of lumbar spine stabilizer muscle strength. Both of these tests have been shown to be extremely reliable with repeated tests on five consecutive days producing reliability coefficients of 0.97 and 0.98, respectively (47). In addition, the Biering-Sorensen test has been shown to be a valid test for assessing torso stabilizing musculature as it can discriminate between subjects with and

without nonspecific low back pain (49). No previous studies on firefighter populations have reported data from these types of tests.

Vertical jump height has long been used in athletics as a way of assessing force production and more specifically, lower body power (50). Coaches and athletes often use maximum vertical jump height as an index of athletic performance because it is an inexpensive and simple field test to perform (51). One of the most common field methods for assessing vertical jump is the Sargent test (52), in which the difference between standing reach height and jumping reach height with a countermovement arm swing is calculated to determine vertical jump. The Sargent test has been shown to be both a reliable (intraclass correlation coefficient = 0.96) and valid ($r = 0.8$) method of assessing explosive muscle power (51). As previously reported, only limited data is available with regard to firefighter performance on the vertical jump (28).

Maximal exercise testing as long been considered the standard for assessing aerobic power by way of a VO_2 max test (53). In theory, combining a maximum effort test with measurement of breath-by-breath gas exchange allows for the most accurate account of cardiorespiratory fitness. This type of test was performed in the current study on a treadmill using a modified Bruce protocol (54) in which grade and speed were increased in a stepwise manner until voluntary exhaustion was achieved. A limitation in using any maximal performance VO_2 max test includes musculoskeletal fatigue prior to achieving VO_2 max (53), but the modified Bruce protocol used involves small increases in workload at each stage, such that excellent reliability is achieved with correlation coefficients of $r = 0.94$ for men and $r = 0.93$ for women without any type of cardiac condition (53). Anaerobic threshold can be measured using

either blood sampling methods or noninvasively using gas exchange methods (55). One method of estimating the anaerobic threshold is to look for the inflection point of the V_E/VO_2 curve (volume of air expired/volume of oxygen consumed) when plotted against work. The sharp increase in the slope of the line reflects a disproportionate increase in the amount of air exhaled without an accompanying increase in the volume of oxygen consumed (10). Physiologically, the body is becoming increasingly acidic from an increased reliance on anaerobic metabolism due to an unsustainable work rate. In an effort to combat this, breathing rate is increased to exhale excess carbon as carbon dioxide and reduce acidic compounds in the body. Studies in the past have looked at VO_2 max in firefighters (3,5,13–19) but anaerobic threshold data has not previously been reported.

2. Objectives

The current study was descriptive in nature and aimed to fulfill three objectives:

1) To gather data regarding the physical fitness of active firefighters

2) To determine whether a predictive testing battery could be developed to assess work performance and injury risk

3) To make recommendations regarding the composition of physical fitness training and testing programs for firefighters

Many previous studies focusing on the fitness of firefighters have heavily utilized new recruits or those with little experience (3,5,14,28) and predictably these samples produced excellent fitness results. The aim of this study was to test a sample of firefighters with a wide range of ages in order to gain a more accurate assessment of the fitness of "average" active, mid-career firefighters serving an urban area. In addition, there is limited Canadian data regarding firefighter health and fitness and this study will set the necessary foundation to develop a Canadian database of firefighter physical fitness variables.

Correlations between the various fitness measurements were also examined with a view towards seeing if a simple set of tests may suffice to predict physical fitness and potentially injury risk in this population without the need for continued use of more sophisticated measures, such as those used in the present study. Identifying field tests that can substitute for more complicated technical tests with reasonable accuracy is critical in producing a testing battery that will be adopted by fire departments.

Finally, the data collected also has the potential to inform future direction of firefighter training programs to address potential shortcomings in fitness for job performance and overall

health-related quality of life. By having some baseline variables on which to base a training

program, the quality and effectiveness of it is inherently increased. Rather than using a generic

approach to designing a program, one can specifically tailor the program to focus on areas of

weakness to increase overall fitness level.

3. Methodology

Participants were recruited from fire stations under the jurisdiction of the Kitchener Fire Department (KFD). Written informed consent was obtained from all participants and participation in the study was completely voluntary, the results of which would be confidential and reported only in aggregate so that testing would be devoid of any impact on their career. Study design and recruitment was reviewed and accepted by the Wilfrid Laurier University ethical review board (REB #3640). In addition, the KFD Health Promotion Committee, with representatives from the KFD management and workers' union, also approved the study design and Dr. Peter Tiidus of Wilfrid Laurier University supervised all research design.

3.1 Subjects

To be included in the study, potential participants must have been active members of the fire suppression unit of the KFD. They were required to complete an informed consent form, screening form, and CSEP Physical Activity Readiness Questionnaire (PAR-Q) (33). Exclusionary criteria included having been advised by a medical professional to not participate in vigorous physical activity, not being able to perform all of the physical demands of their job as a result of a musculoskeletal issue, or answering "Yes" to one or more questions on the PAR-Q.

Firefighters were first recruited by way of a letter sent out by the KFD inviting them to participate in a study looking at various measures related to health and fitness. Those who wished to participate were tested at the KFD headquarters. After an initial round of recruitment a second follow-up letter was distributed and the researcher targeted and went to specific fire stations where participation was low to recruit additional participants and perform testing.

Testing took place over three separate sessions in which unique tests were administered. 49 subjects (47 male, 2 female) were tested at their fire stations for the first session. One potential participant was excluded as a result of the exclusionary criteria. The second session was performed at Wilfrid Laurier University (WLU) and 24 firefighters were tested. The final session also took place at the University, with 23 (22 male, 1 female) of the original 49 subjects completing all three testing sessions. Each session took approximately one hour to complete.

3.2 Session 1

The first testing session at the fire stations focused mainly on baseline physiological testing and was done to also better establish rapport with the participants before requiring them to come to the University for further testing. After the screening and informed consent forms were obtained, height and weight measurements were taken. Height was measured using a generic measuring tape taped to a flat wall to the nearest 0.5 cm using a flat board to mark the point at which the top of the subject's head reached the measuring tape. Weight was measured to the nearest 0.1 kg using a body composition scale in light clothing without shoes on. Participants were then asked to remove their shirt and sit in a chair for measurement of resting heart rate and blood pressure. A three-lead electrocardiograph was used to measure heart rate and a sphygmomanometer was fitted over the subject's left arm, just above the elbow for blood pressure measurement of the brachial artery. Subjects were instructed to remain relaxed throughout the measurements and were allowed to sit quietly in the chair for a couple minutes prior to taking any readings in order to allow for heart rate and blood pressure to stabilize. Three measurements were taken of each variable with the lowest being recorded.

Waist circumference was measured on the right-hand side of the body to the nearest 0.5 cm using a generic measuring tape at the superior border of the iliac crest (56). In the event that this point could not be visualized the navel was used as a reference point. Participants were instructed to cross their arms across their chest and stand relaxed with feet parallel and shoulder-width apart and the measurement was taken at the end of a normal exhalation. Skinfold thickness was measured on the right-hand side of the body using Harpenden calipers to the nearest 0.2 mm using the overhand technique so that the caliper jaws were applied at 90° to the skinfold 1 cm below the landmark at five sites: biceps, triceps, subscapularis, iliac crest, and medial calf. Each site was measured a minimum of two times to obtain an average. Measurements were repeated in the same order to allow for the skin to regain its elasticity and if measurements differed by ≥ 0.4 mm a third reading was taken and all three were averaged. Skinfold measurements of the biceps, triceps, subscapularis, and iliac crest were used to calculate body fat percentage according to the Durnin-Womersley method (57) based on body density using Siri's equation (58):

% fat = (4.95/density – 4.50) x 100 (1)

Equations used to calculate body density differed for various age groups and gender (please see Appendix 7.6 Body Density Estimation Equations for all body density equations) (57). Height, weight, waist circumference and all five recorded skinfold thickness measurements were used to calculate the Canadian Physical Activity, Fitness, and Lifestyle Appraisal (CPAFLA) Health Body Composition Score (59). Calculating the CPAFLA Healthy Body Composition Score involves determining whether BMI, waist circumference, the sum of five skinfolds (biceps, triceps, subscapular, iliac crest, and medial calf), and the sum of two trunk skinfolds (subscapular and iliac crest) are in a predetermined "healthy" or "unhealthy" range based on criteria from

CPAFLA (please see Appendix 7.7 CPAFLA Healthy Body Composition Score Criteria for charts with predetermined healthy ranges). Skinfolds were landmarked and assessed using standard procedures (57,60). The biceps and triceps were landmarked by having the participant flex their elbow to 90° with the palm supinated and the midpoint between the distal tip of the acromion process and the olecranon process was marked. The midpoint level was then transferred to the front and the back of the arm to obtain the landmark for the biceps and triceps, respectively. Skinfolds for the biceps and triceps both ran vertically. The subscapcularis was landmarked 1 cm below the inferior angle of the scapula and the skinfold ran downwards and outwards at a 45° angle to the spine. To landmark the iliac crest the participant was first instructed to raise the right elbow, place the right hand on the shoulder, and not bend to the side as this can distort the skin, and subsequently the landmark. The landmark was placed 3 cm above the iliac crest at the axillary midpoint of the body with the skinfold running forward and slightly downward. The medial calf landmark was obtained by having the participant unload their right leg on a chair with the knee bent at a 90° angle. At maximum calf girth the landmark was placed along the midline of the medial side of the calf with the skinfold running vertically.

Participants then completed the Functional Movement Screen (FMS), a seven-movement assessment used to identify compensatory movements in the kinetic chain of movement patterns (39). Each movement was scored from 0-3 with higher scores being better. A score of 3 indicates that the movement was performed without any compensatory movements while a 2 indicates that some type of minor compensation was required. If a participant cannot perform a movement a score of 1 is given. If the participant complains of pain at any time during a movement, a score of 0 is assessed. In bilateral movements the lower of the two scores is recorded for the

movement. In addition, some movements have an additional clearing test associated with them. If the participant experienced pain during the clearing test a score of 0 was assessed for the corresponding movement (please see Appendix 7.7 Functional Movement Screen Movement Patterns & Scoring Criteria for images of all seven components and clearing tests).

The first component of the FMS was the Deep Squat (39). Participants were instructed to hold a dowel with both hands overhead with arms fully extended. With feet roughly shoulder-width apart, parallel, and toes pointed forward, they descended into a deep squat so that the thighs broke parallel with the floor. The torso should be parallel with the tibia in the lowered position and the dowel, knees, and feet aligned. To perform the bilateral Hurdle Step, a hurdle was set up at the height of the subject's tibial tuberosity and a dowel was held across the shoulders with the feet shoulder-width apart and toes touching the base of the hurdle. Subjects were instructed to step over the hurdle without touching it while maintaining an upright posture, touch the heel to the floor and return to the starting position. The hips, knees, and ankles should remain aligned in the sagittal plane and the dowel and hurdle should remain parallel throughout the movement. The In-Line Lunge was performed with a dowel held vertically behind the back with one hand against the back of the neck and the other hand against the lower back. The feet were placed in-line at a distance of the tibial tuberosity and subjects were instructed to descend into a lunge so that the knee touches the floor while maintaining an upright posture and constant contact of the dowel against the head, thoracic spine, and sacrum. The torso should not move and the dowel and feet should remain in the sagittal plane while the knee touches the floor directly behind the heel. The bilateral Shoulder Mobility movement involved making a fist with the thumb tucked in and then, in a single motion, placing one hand over the head onto the back and

the other hand behind the back as close together as possible. If the fists were within one hand

length of each a perfect score of 3 was given while a 2 was recorded if the fists were within 1.5

hand lengths. The Impingement Clearing Test required participants to place their hand on the

opposite shoulder and raise the elbow toward the forehead while maintaining hand placement.

The bilateral Active Straight Leg Raise was performed laying down face-up by lifting one

straight leg towards the torso as much as possible while keeping the other leg extended on the

floor. The ankle of the raised leg needed to be superior to the mid-thigh of the relaxed leg for a

score of 3. If the ankle fell between the mid-thigh and knee a 2 was given and if the ankle was

below the knee joint a 1 was assessed. The Trunk Stability Pushup was performed in the standard

pushup position with the hands positioned shoulder-width apart. Males placed the thumbs in line

with the forehead while females placed the thumbs in line with the chin. Maintaining a rigid

torso, participants raised their body off of the floor as one unit with no lag. If participants could

not perform the pushup as described, males moved the hands to a position in line with the chin

and females moved the hands to a position in line with the clavicle for a score of 2. The Press-Up

Clearing Test was performed from the lowered pushup position with the hands palm-down

beneath the shoulders. Participants pressed the chest off of the floor, arching the back as much as

possible while keeping the hips in contact with the floor. The final movement performed of the

FMS was the bilateral Quadruped Rotary Stability task. Participants positioned the shoulders and

hips at 90° and attempted to lift the same side arm and leg off the floor, extend the limbs

simultaneously, and then flex the limbs to touch the elbow and knee together all while

maintaining a flat back position. If a unilateral rep could not be performed a diagonal rep was

attempted to score a 2. The Posterior Rocking Clearing Test was performed by maintaining

contact with the hands on the floor, rocking back on the heels so that chest reached towards the knees, and extending the arms in front of the body.

The final test performed during session 1 at the fire stations was the ACSM Pushup Test (43). Participants started in the standard pushup position with hands pointed forwards under the shoulder, back straight, head up, and the toes acting as the pivot point with the floor (females begin in a modified pushup position with their knees contacting the floor rather than toes) and performed as many consecutive pushups as possible without rest. A successful pushup involved the participant straightening the elbows to raise the torso off of the ground and then lowering down until the chin touched the floor (note that the chest should not touch the floor at any time).

3.3 Session 2

When participants first arrived at WLU for the second testing session their weight was measured to the nearest 0.1 kg in light clothing without footwear. The first test performed was the 60° abdominal muscle endurance test (47). Participants laid down, face-up, with their legs bent and feet wedged underneath a bike frame. They folded their arms across their chest and kept their back straight while the experimenter adjusted their upper body to a 60° angle using a goniometer. Participants were instructed to maintain this position and given feedback when they deviated from 60° so that minor corrections could be made.

Measures of maximum strength for both the lower and upper body were next assessed. Participants performed a 60°/s, isokinetic, concentric quadriceps contraction using a human dynamometer followed by a biceps contraction of the same variety. Torque production has previously been measured using concentric contractions at 60°/s (61,62) and has been shown to be quite reliable at this speed with mean variation test-retest results being $4.7 \pm 0.96\%$ (95% CI:

3.6, 6.1%) (61). Once the equipment was set-up per its directions, three practice repetitions were performed to allow subjects to become acquainted with the machine. After a 30 s rest period three maximum effort contractions were performed and the peak torque produced in any of the repetitions was recorded.

The last assessment of the first testing session at WLU was the Wingate Anaerobic Test (44). Brake weight was set at 7.5% of the participant's body weight, as measured that day at the beginning of the testing session. Prior to the Wingate test, participants warmed up using a cycle ergometer for approximately 7 min at 1-2 kp resistance. At approximately 5 and 6 min into the warm-up a short 5 s sprint against the approximate resistance of the Wingate test was performed to allow participants to become acquainted with the load. Following this, participants transferred to the Wingate cycle ergometer and began cycling without any resistance. Toe-clips were used and participants were instructed not to leave the seat during the test as this can increase test performance by up to 8% as well as reducing standardization and therefore, reliability (45). Once participants reached maximum cycling speed, a button on the handlebar was pressed to engage the brake weight and begin the 30 s test timer. Participants were verbally encouraged to maintain maximum effort throughout the test duration and following the test a 10 min cool down on a cycle ergometer was performed plus a short walk to ensure that no negative symptoms developed.

3.4 Session 3

As with the previous two sessions, the third and final testing session at WLU began with weight measured to the nearest 0.1 kg in light clothing without footwear. The Biering-Sorensen test (48), which measures back extensor muscle endurance, was then administered by having the

participants lie face down on a table with their upper body hanging off the edge while the experimenter applied pressure to their lower legs to stabilize them. Participants then crossed their arms on their chest, brought their upper body in-line with their lower body, and maintained this straight body position for as long as possible.

Vertical jump was then assessed from a standing, two-footed takeoff with countermovement arm swing as outlined in the Sargent test protocol (51). A commercial vertical jump measurement tool with a 2 ft (60.96 cm) measuring area (by way of vanes separated by 1 in [2.54 cm]) was adjusted so that it was at the level of the participant's overhead raised arm's fingertip. Participants were given three opportunities to jump and swipe a vane with their hand and the highest jump was recorded as this method is often used in athletic settings and there is a motor learning effect present (50). In the event that a participant's vertical jump was greater than 2 ft (60.96 cm), the measurement device was set to a known height and their standing reaching height was measured prior to jumping.

The final test performed was a VO_2 max treadmill test to assess aerobic power. Participants were outfitted with a mask hooked up to a metabolic cart to measure breath-by-breath gas exchange in addition to a 4-lead electrocardiograph to track heart rate over the duration of the test. Participants were instructed to remain running on the treadmill for as long as safely possible. The testing protocol was based on the Bruce protocol (54), began at a walking pace, and grade was increased by 2% every 1 m 30 s with small increases in speed until voluntary exhaustion (for full testing protocol please see Appendix 7.6 Modified Bruce Protocol for VO_2 max Treadmill Test). The respiratory exchange ratio (RER) was recorded at the time of exhaustion. Anaerobic threshold was also recorded by determining the inflection point of the $V_E/$

VO$_2$ curve (volume of air expired/volume of oxygen consumed) and heart rate was also recorded at this point.

Data was presented as mean ± standard deviation and ranges also given. Where appropriate, data was normalized to allow for comparison between people of different body sizes. Sub-analysis by decade-long age groups was also performed. Assumptions of statistical normality were checked using estimates of skewness and kurtosis as well as the Kolmogorov-Smirnov test. Statistical testing using SPSS 21 software comprised of Pearson's correlation coefficients and one-way ANOVAs for between group differences based on age. Statistical significance was set at the two-tailed, $p < 0.05$ level.

4. Results

All three testing sessions of the study were completed by only 23 participants out of 49 people who began the study and completed the first session, yielding a ~ 47% completion rate. There are about 150 active firefighters in the KFD. Only one subject completed the second session but did not return for the final third session. Initially, two females were recruited for the study but only one completed all three sessions. Due to this, their data was grouped in with the rest of the male data and comparisons were made to male populations where applicable.

Descriptive statistics of procedures performed, including mean, standard deviation, and range are displayed in Table 1. Of particular interest are some of the low-end ranges of some variables, such as with VO_2 max. Though aerobic capacity averaged 42.2 ± 6.6 ml O_2/kg/min for the group as a whole, the lower end of the data reaches 27.3 ml O_2/kg/min. The RER at test conclusion was found to be 1.2 ± 0.1, indicating the absence of steady state. We can then be reasonably confident that our group attained VO_2 max during their test, as their RER was > 1.15, which is generally accepted as the threshold point for differentiating between a VO_2 max and VO_2 peak (4). VO_2 max values as well as VO_2 at the anaerobic threshold (33.3 ± 8.2 ml O_2/kg/ min) were expanded to show individual values in ascending order in Figures 1 and 2, respectively. Peak power produced during the Wingate test (10.6 ± 1.1 W/kg) and average power produced (7.4 ± 1.0 W/kg) were also expanded out in increasing order in Figures 3 and 4, respectively.

Normality of the measures was assessed in three ways: subjectively with P-P plots and objectively using Kolmogorov-Smirnov tests and z-scores of skewness and kurtosis. Abdominal muscular endurance, $D (24) = 0.2$, $p = 0.014$, was the only variable with a non-parametric

distribution, in addition to z-scores for skewness and kurtosis of 3.37, $p < 0.001$ and 2.09, $p < 0.05$, respectively. This indicates that distributions for variables other than abdominal muscular endurance are parametric and inform the type of correlation statistics used. It also indicates that the distribution of scores in the various assessments reported for the firefighter populations were for the most part normally distributed without undue skewing at the lower or higher ends.

Correlations were performed in hopes of determining which variables may best predict performance in most other variables. Pearson's *r* correlation statistic was used because variables had a parametric distribution of the data (63). Body fat percentage correlated with the most other variables while resting blood pressure, height, and abdominal muscular endurance had the fewest amount of significant correlations. Weight displayed a strong, positive correlation with both BMI ($r = 0.86$, $p < 0.001$) and waist circumference ($r = 0.83$, $p < 0.001$), as did waist circumference with BMI ($r = 0.88$, $p < 0.001$). Body fat percentage had a significant negative correlation with almost all of the performance measures save for abdominal flexor and back extensor muscular endurance (see Table 2 for correlations), potentially hinting at its use as a general predictor of fitness and performance. Quite predictably, the CPAFLA Healthy Body Composition score had strong negative correlations with the variables that factor into it: body fat percentage ($r = -0.72$, $p < 0.001$), waist circumference ($r = -0.71$, $p < 0.001$), and BMI ($r = -0.62$, $p < 0.001$). Total score in the FMS displayed modest, negative correlations with many of the body composition variables (see Table 3 for correlations), specifically weight, BMI, waist circumference, and body fat percentage, while correlating positively with CPAFLA score.

Pushup repetitions correlated most with maximum bicep strength ($r = 0.62$, $p = 0.001$) in addition to strong positive relationships with other performance measures. Maximum quadriceps

strength has strong positive correlations with Wingate peak power ($r = 0.7$, $p < 0.001$), vertical jump ($r = 0.62$, $p = 0.002$), and VO_2 max ($r = 0.61$, $p = 0.002$). Wingate test peak power production had strong, positive correlations with many of the performance variables (see Table 4 for correlations), specifically vertical jump ($r = 0.75$, $p < 0.001$). Vertical jump also correlated strongly with many of the other performance measures (see Table 5 for correlations). Unsurprisingly, VO_2 max exhibited strong, positive correlations with VO_2 at anaerobic threshold ($r = 0.84$, $p < 0.001$), Wingate peak power ($r = 0.63$, $p = 0.001$), and maximum quadriceps strength. However, when VO_2 at the anaerobic threshold was expressed as a percentage of VO_2 max the two variables surprisingly did not correlate ($r = 0.37$, $p = 0.079$).

One-way ANOVAs were performed to look for differences in VO_2 max and Wingate test peak power production values based on differences in decade-long age groups. No significant difference was found for either VO_2 max ($F_{(3,19)} = 1.42$, $p = 0.27$) or Wingate test peak power ($F_{(3,20)} = 1.46$, $p = 0.26$). However, VO_2 max did display a significant negative correlation with age, as shown in Figure 7 ($r = -0.5$, $p = 0.015$).

Table 1. *Baseline and physical fitness characteristics of firefighters*
Subject number, mean, standard deviation, minimum, and maximum values for all data collected.

	N	Mean	SD	Minimum	Maximum
Age (years)	49	40.5	8.3	26	55
Resting Heart Rate (bpm)	49	57.7	8.2	40	74
Resting Systolic Blood Pressure (mm Hg)	49	121.5	11.9	100	149
Resting Diastolic Blood Pressure (mm Hg)	49	71.5	9.9	48	96
Height (cm)	49	179.2	6.6	166.5	196.0
Weight (kg)	49	89.5	13.0	64.3	126.1
Body Mass Index (kg/m	49	27.8	3.6	21.7	37.3
Waist Circumference (cm)	49	93.5	10.1	79	123
Body Fat (%)	49	24.2	5.4	14.7	37.9
CPAFLA Healthy Body Composition Score	49	7.6	6.8	0	15
Functional Movement Screen (total score)	49	15.6	1.6	11	19
60° Abdominal Endurance Test (s)	24	153.8	94.2	64	407
Biering-Sorensen Test (s)	23	113.4	48.6	24	231
ACSM Pushups (repetitions)	49	31.4	11.6	8	60
Vertical Jump (cm)	22	50.0	9.6	33	66
Quadriceps Strength (Nm/kg)	24	3.0	0.7	1.9	4.2
Bicep Strength (Nm/kg)	24	1.0	0.1	0.7	1.2
Wingate Test Peak Power (W/kg)	24	10.6	1.1	8.5	12.3
Wingate Test Average Power (W/kg)	24	7.4	1.0	5.2	8.8
Wingate Test Minimum Power (W/kg)	24	5.3	1.0	3.5	6.7
Wingate Test Fatigue Index (%)	24	49.7	8.7	31.3	64.5
VO$_2$	23	42.2	6.5	27.3	52.8
Anaerobic Threshold VO	23	33.3	8.2	18.4	47.3
Anaerobic Threshold VO	23	78.1	11.5	57.0	96.0

Table 2. *Correlations between body fat percentage and performance variables*

	r Value	p Value
ACSM Pushups	- 0.61	< 0.001
Quadriceps Strength	- 0.58	0.003
Bicep Strength	- 0.56	0.005
Wingate Test Peak Power	- 0.55	0.005
Wingate Test Average Power	- 0.62	0.001
Wingate Test Minimum Power	- 0.51	0.012
Vertical Jump	- 0.72	< 0.001
VO$_2$	- 0.44	0.037
Anaerobic Threshold VO	- 0.53	0.009

Table 3. *Correlations between Functional Movement Screen total score and body composition variables*

|	r Value	p Value
Weight	- 0.36	0.01
Body Mass Index	- 0.48	< 0.001
Waist Circumference	- 0.47	0.001
Body Fat Percentage	- 0.48	< 0.001
CPAFLA Healthy Body Composition Score	0.48	0.001

**Table 4.** *Correlations between peak power production during the Wingate test and performance variables*

	r Value	p Value
ACSM Pushups	0.53	0.008
Quadriceps Strength	0.7	< 0.001
Bicep Strength	0.53	0.007
Wingate Test Average Power	0.74	< 0.001
Wingate Test Minimum Power	0.43	0.037
Vertical Jump	0.75	< 0.001
VO$_2$	0.63	0.001
Anaerobic Threshold VO	0.57	0.004

Table 5. *Correlations between vertical jump and performance variables*

	r Value	p Value
ACSM Pushups	0.58	0.005
Quadriceps Strength	0.62	0.002
Bicep Strength	0.73	< 0.001
Wingate Test Peak Power	0.75	< 0.001
Wingate Test Average Power	0.8	< 0.001
Wingate Test Minimum Power	0.6	0.003
VO$_2$	0.67	0.001
Anaerobic Threshold VO	0.78	< 0.001
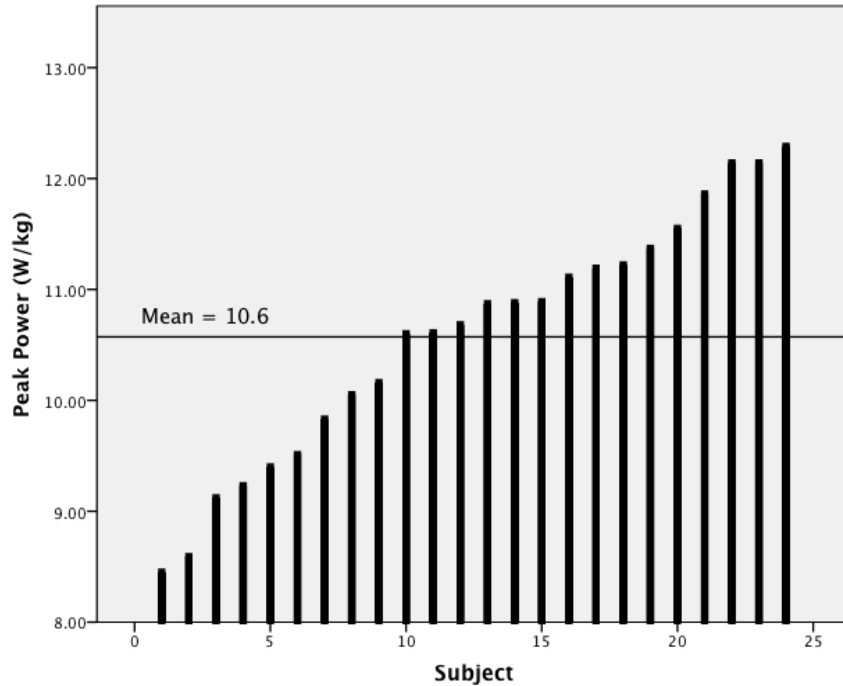
Figure 1. *Individual Wingate test peak power production*
Relative power production in W/kg of all subjects (N = 24) during 5 s period of peak revolutions during the Wingate test in ascending order.
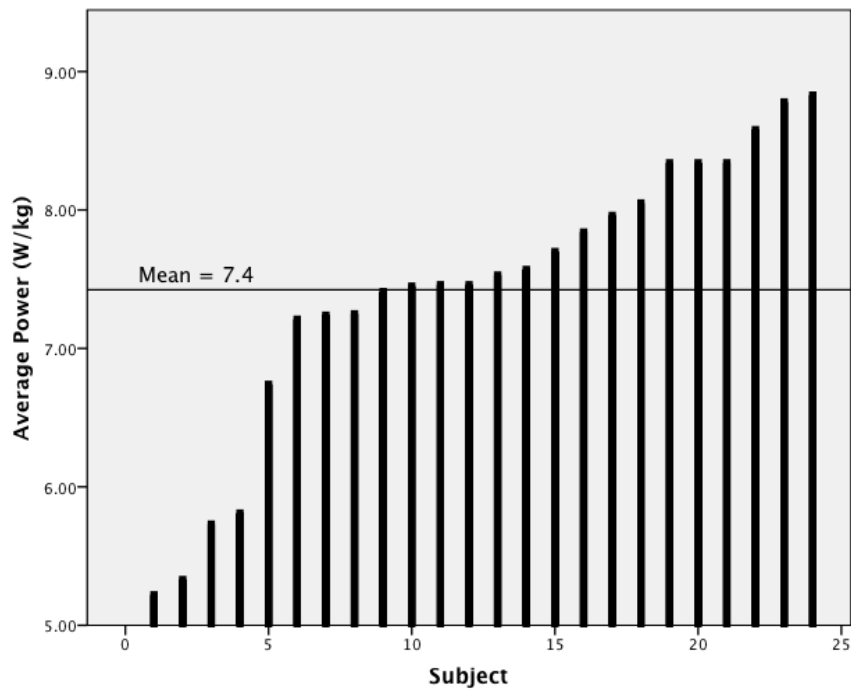
Figure 2. *Individual Wingate test average power production*
Relative power production in W/kg of all subjects (N = 24) during 30 s Wingate test in ascending order.
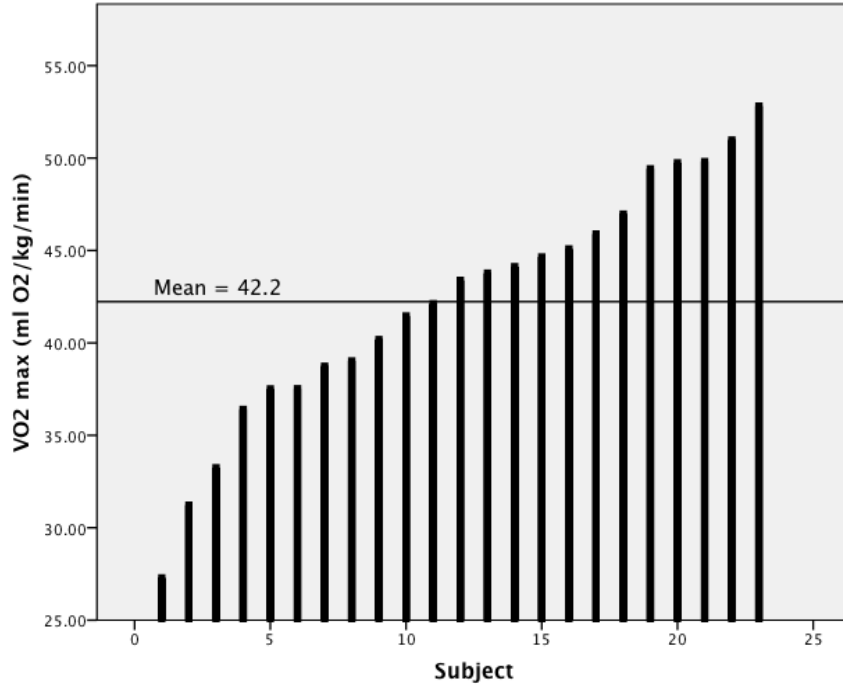
Figure 3. *Individual VO₂ max during treadmill test*
Relative VO$_2$ max in ml O$_2$/kg/min achieved during treadmill test of all subjects (N = 23) in ascending order.
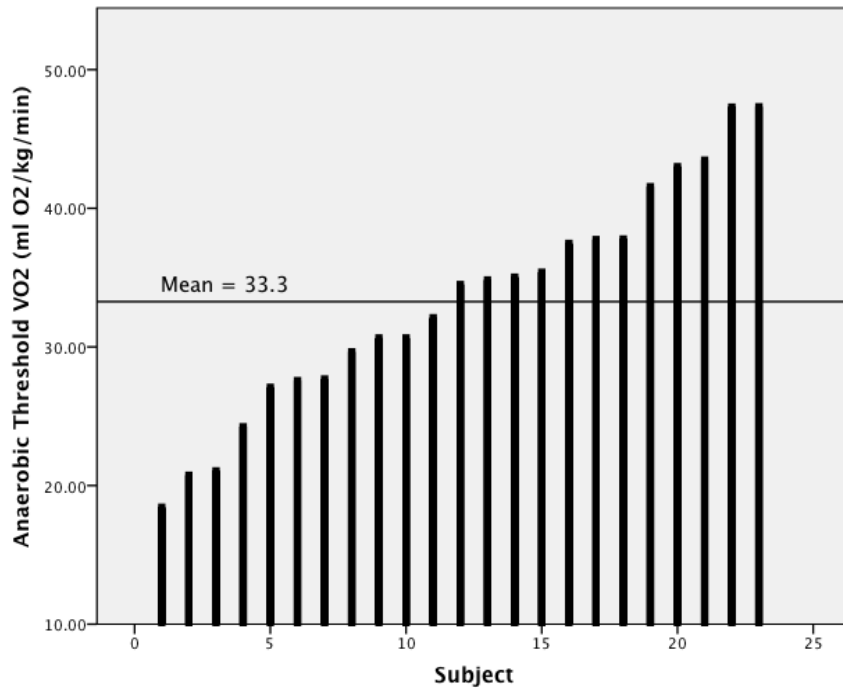
Figure 4. *Individual VO₂ at the anaerobic threshold during treadmill test*
Relative VO$_2$ in ml O$_2$/kg/min at the anaerobic threshold achieved during treadmill test of all subjects (N = 23) in ascending order.
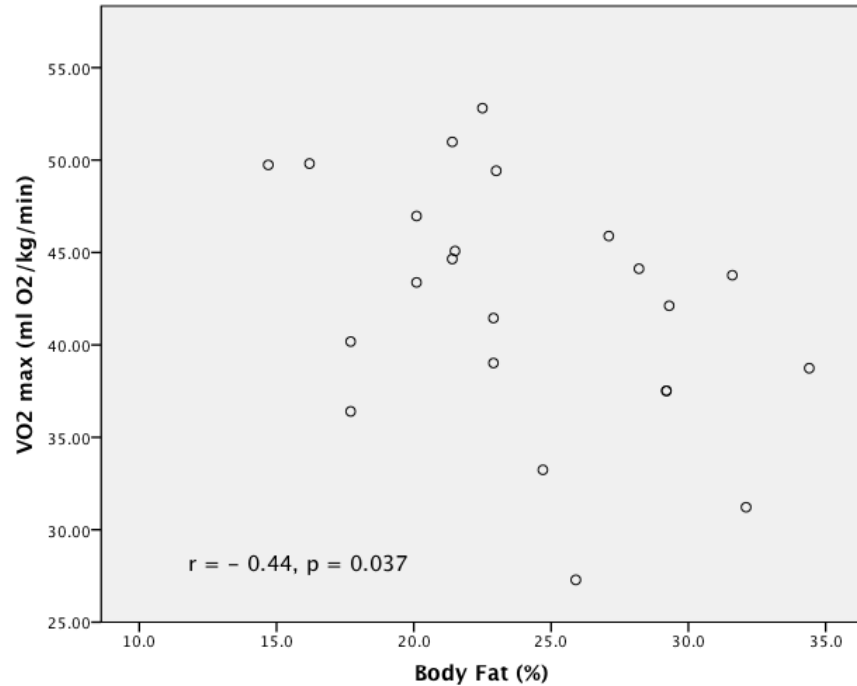
Figure 5. *Correlation between body fat and VO₂ max*
Scatter plot of body fat (%) and relative VO$_2$ max (ml O$_2$/kg/min) showing a negative correlation (r = - 0.44, p = 0.037).
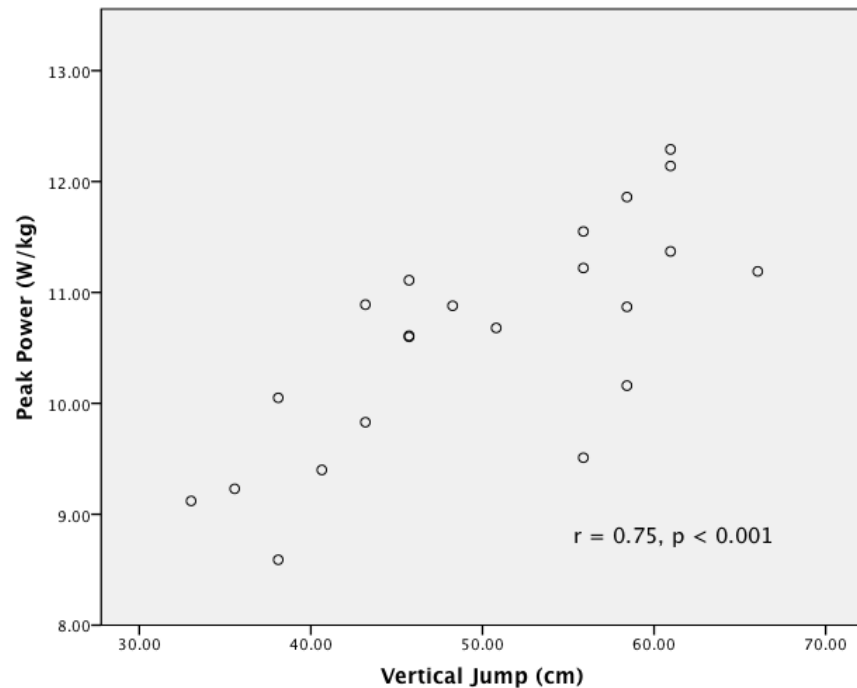
Figure 6. *Correlation between vertical jump and Wingate test peak power production*
Scatter plot of maximum vertical jump height (cm) and peak power produced (W/kg) during the Wingate test showing a positive correlation (r = 0.75, p < 0.001).
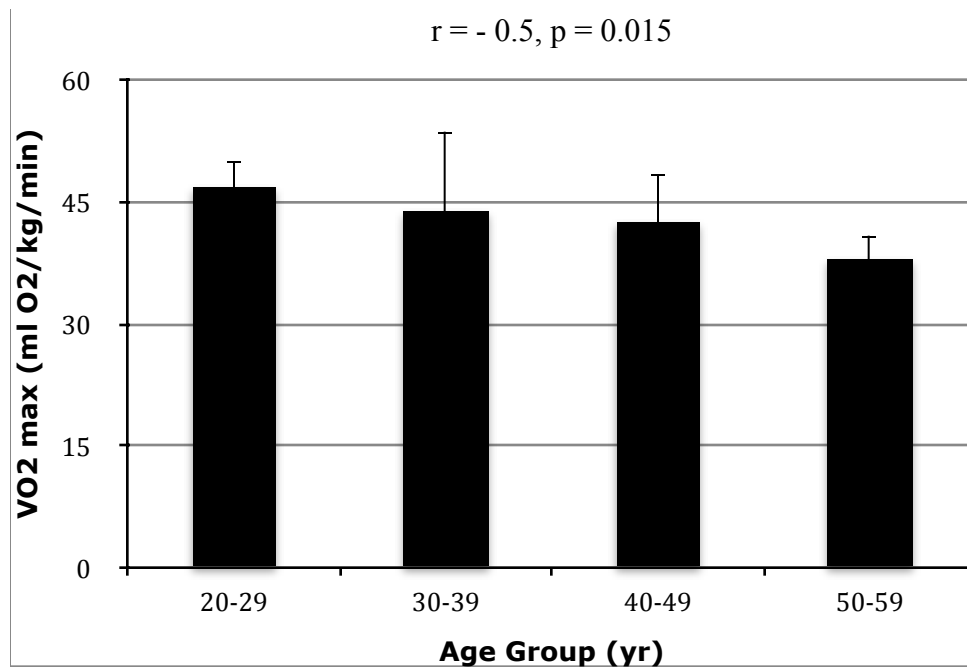
Figure 7. *Relationship between VO₂ max and age*
Bar graph of relative VO$_2$ max (ml O$_2$/kg/min) and age (years) grouped into decade-long cohorts. A negative correlation as found between VO$_2$ max and age (r = - 0.5, p = 0.015).

5. Discussion

The average age of this sample of firefighters was 40.5 ± 8.3 years old. This is important and worth noting because the target sample group was active firefighters with a wide range of service time and age in order to gain a more accurate snapshot of the physical fitness level of "average" experienced firefighters of a wider age range, rather than just a younger group who more recently had to complete the physical fitness testing to become a firefighter. When appropriate and possible, references to normative population data or previous literature were done using males in the 40 – 49 year old age range in order to gain the most applicable and relatable bases for comparison.

Though largely descriptive in nature, the present study highlights several interesting trends in the current fitness level of an active urban-area firefighter population. VO_2 max was found to be 42.2 ± 6.5 ml O_2/kg/min, superficially appearing very much in line with the standard previously established for firefighting of 42 ml O_2/kg/min (13,14). However, when individual VO_2 max values were examined, as in Figure 1, it was seen that many firefighters actually fall below the cardiorespiratory standard and in fact there may be a small, but significant, portion of this population that is physically unfit to perform the duties of their job expected of them. Part of being a firefighter involves maintaining one's fitness and ideally even those with lowest cardiorespiratory fitness should still be greater than the minimum standard and if a number of firefighters fall significantly below this standard this may be a cause for concern. It should be noted that this particular sample was not alone in their less than ideal aerobic work capacity as previous studies using an active firefighter have also reported average VO_2 max values below 42 ml O_2/kg/min (18,19). Also, though this sample tested better than reference adult males in the

same age range (38.1 ml O_2/kg/min) (23), it is expected that those in a public safety profession such as firefighting would maintain a better fitness level than their counterpart in the population as there is a large physical fitness component to their job. Though no significant difference was found in VO_2 max based on differences in age (F $(3,19) = 1.42$, p $= 0.27$), there was a negative correlation between age and VO_2 max (r $= - 0.5$, p $= 0.015$), suggesting that aerobic fitness capacity declines with age.

Predictably, VO_2 consumed at the anaerobic threshold followed similar patterns to VO_2 max and the two measures have a strong positive correlation (r $= 0.84$, p < 0.001). Quite surprisingly, when VO_2 at the anaerobic threshold was expressed as percentage of VO_2 max (78.1 $\pm 11.5\%$) the two variables did not significantly correlate. Exercise training usually produces gains in VO_2 max and both absolute and relative VO_2 at the anaerobic threshold so that one is able to sustain work performance at a higher percentage of absolute VO_2 max (4). Since there was a modest trend towards statistical significance between the two variables (r $= 0.37$, p $= 0.079$), a greater sample size may have been needed to achieve significance of the expected relationship. As with VO_2 max, it is most interesting to note the wide spread of the data regarding VO_2 at the anaerobic threshold, which ranged from 18.4 – 47.3 ml O_2/kg/min. The anaerobic threshold is a good predictor of actual sustained work performance (4), and looking again at the lower range values, the results are somewhat concerning. Converting 18.4 ml O_2/kg/min to METs gives approximately 5.3 METs, which would correspond to a slow jog or brisk walk at about 6.5 km/h (64). This is then the intensity of work that the individual at this low end could sustain for a significant period of time. Firefighters will often need to perform work that is sustained for significant periods of time at intensities greater than 5 METs, and having a

maximum capacity to perform work at 12 METs has previously been recommended as the minimum necessary to be a firefighter (13,14). This further highlights the possibility that a small portion of this sample may not possess the requisite fitness level to perform their job responsibilities adequately. The mean VO_2 at the anaerobic threshold was found to be 33.3 ml O_2/kg/min, which can be converted to approximately 9.5 METs. This corresponds to jogging at about 9.5 km/h (64), which can be thought of as the average, sustainable work capacity of this sample of firefighters. Looking at a population's VO_2 at the anaerobic threshold may prove valuable in predicting the level of work performance that can be sustained for a significant period of time (4) and has not been previously reported in firefighters. This important new information will add to the available data on the quantification and assessment of firefighter fitness and work capacity.

The trends seen regarding age and both VO_2 max and VO_2 at the anaerobic threshold seemingly highlight the need for continuous firefighter training programs to combat the age-related decline in fitness. Currently, fire departments for many large, urban areas only require a physical fitness test which individuals need to pass to qualify for employment (1). Though active firefighters are encouraged to maintain their fitness and often are provided with the facilities to do so while on shift, they do not perform any further formal fitness testing for the duration of their careers and there are few formal fitness training programs provided for firefighters. The insight and data provided by the current study may help to inform development of future training programs designed specifically for firefighters to target areas of weakness. Having accurate baseline data helps to increase the efficiency of any training program and this is especially valuable to a fire department where funds allocated for fitness training may be limited.

Peak power produced during the Wingate test averaged 10.6 ± 1.1 W/kg for the firefighters measured. Some previous studies that have performed Wingate tests using either male or female firefighters (28,31) have reported only absolute values and only Murphy et al. (1984) observed male firefighters achieving 750.4 W of power produced at peak (31). By very crudely multiplying peak power and weight, we calculated that this sample of firefighters might have been able to maximally produce about 948.7 W during the Wingate test. A group of active firefighters, as used in the present study, has been observed to produce 9.4 ± 0.3 W/kg at peak revolutions during the Wingate test (65). By expressing power output using a relative measure (work per kilogram of body weight), our study adds additional value not presently seen in past studies by allowing for direct comparisons to other groups, even in cases where body sizes may differ significantly. Though this group of firefighters performed better than other firefighters, other potential comparator groups such as male intercollegiate (NCAA) athletes are able to produce more power during the Wingate test, 11.65 W/kg (32). This sample of firefighters appears to have adequate power to perform their job duties although no standard has been set for anaerobic power as it has with aerobic power. As with VO_2 max, there was not a significance difference for age having an effect on Wingate test peak power ($F_{(3,20)} = 1.46$, $p = 0.26$). Mean power produced in the Wingate test averaged 7.4 ± 1.0 W/kg and converting to an absolute value was estimated to be approximately 662.3 W. Hence this group performed better than previously reported data of 555.4 W from Murphy et al. (1984) (31).

Most firefighting tasks last 30 seconds or longer, such that a fire department may be more interested in its firefighters' average power production rather than peak power for the purposes of predicting performance in an emergency situation, which most likely will be in the duration of

minutes rather than seconds and favour power endurance over peak power output. Separating out individual scores, as in Figure 4, shows that the vast majority of the sample is within 1 W/kg of the mean but there are a few individuals who fall quite below this, again lending credibility to the notion that there may be a small, but significant, portion of this firefighter sample that may be unfit to optimally perform their job responsibilities. A fire department might be more interested in this knowledge rather than peak power data as it may help inform development of future training programs to target power endurance production, thereby increasing the effectiveness and efficiency (in both time and money) of said program. In addition, fatigue index, or power drop, of the Wingate test was also calculated and determined to be $49.7 \pm 8.7\%$. Fatigue index measures the change in power output between the peak power output during the first few seconds of the test and the minimum power output (5.3 ± 1.0 W/kg). In collegiate cyclist athletes, a fatigue index of 40.9% has been observed (66) during the Wingate test while youth national team basketball players have been observed with a fatigue index of 56% (67). Cyclists are likely much more familiar with a cycle ergometer than firefighters are and also are more well-versed in that modality of training, thus offering a potential explanation for their reduced fatigue in Naharudin & Yusof's study (2013) (66). The fatigue index observed in the current study ranged from 31.3 – 64.5%, indicating that some firefighters experienced little fatigue during the Wingate test while others lost almost two-thirds of their power output. The large range of fatigue experienced is also seen in male intercollegiate athletes, who have reported a similar mean fatigue index of $47 \pm 7.6\%$ and range of 13 – 77% (32). More research is needed in the area of fatigue index to determine the real-world effects of greater fatigue indexes and define what level might constitue excessive fatigue.

Maximum vertical jump was found to be 50.0 ± 9.6 cm and correlated strongly with many other performance measures, as shown in Table 5. Reference Canadian males aged $40 - 49$ years old have been reported to possess a vertical jump of 35 ± 2 cm (68). Since the vertical jump is an easy test to administer with minimal training, equipment, time, and space needed it may be of great use to a fire department to predict or indicate performance and fitness of new and current firefighters in a variety of areas, when more sophisticated and expensive fitness tests, such as the VO_2 max and Wingate tests may be difficult to perform. Logically, this is sound reasoning for the Wingate as both tests emphasize anaerobic power of the lower body. While a treadmill VO_2 max test, such as the one used in the present study, does utilize the lower body musculature to propel one forward, it taxes the cardiorespiratory system more so. Possibly, vertical jump performance may simply be indicative of overall physical fitness and health. Further research is needed in this area to more accurately determine if maximum vertical jump performance is actually a good predictor of both aerobic and anaerobic performance but it may have the potential to do so and hence if validated may eventually serve as a simple predictive test to monitor more than one type of fitness in firefighters.

Maximum strength of the quadriceps muscle was measured via torque production of an isokinetic, $60°/s$, concentric contraction using a human dynamometer and averaged 3.0 ± 0.7 Nm/kg. As previously mentioned, maximum quadriceps strength had strong, positive correlations with many of the performance tests that tax the lower body (Wingate test, VO_2 max test, vertical jump). Unsurprisingly, it correlated most strongly with Wingate test peak power ($r = 0.7$, $p < 0.001$) as both of these tests emphasize maximum power production in the quadriceps. In other words, while force development and production is an integral part of these tests, the speed at

which one can achieve their maximum force production is paramount to achieving a good test result. While quadriceps strength may be useful for predicting performance in other tests, it is probably not as feasible to use in continued testing of large populations (in this iteration, using a human dynamometer) as the previously mentioned vertical jump due to the increased cost and complexity of the equipment required. Maximum quadriceps strength using this methodology has not previously been reported in firefighters. This data is valuable in formulating a full understanding of firefighter fitness and possibly contributing to the formation of an easy to administer battery of tests to quantify the fitness of this population for the purposes of predicting future performance and health outcomes.

As with the quadriceps, a human dynamometer was used to measure torque production of an isokinetic, 60°/s, concentric contraction of the biceps to quantify maximum strength of the muscle. This sample of firefighters was able to produce 1.0 ± 0.1 Nm/kg in the biceps and this measure has not been previously reported in firefighters. Though they focus on antagonist muscle groups, maximum bicep strength had a strong positive correlation with pushup repetitions completed ($r = 0.62$, $p = 0.001$). This relationship may simply be rooted in overall upper-body musculature and fitness as they do not stress the same muscle groups. As with data on quadriceps strength, this new information on biceps strength provides additional knowledge on firefighter fitness. Specifically, a better understanding of the upper-body strength requirements relative to the demands of firefighting is predicated on obtaining real-world, practical data on different upper-body muscle groups, as we performed.

As another measure of upper-body musculature, but instead focusing more on muscular endurance (43), repetitions in the ACSM pushup test averaged 31.4 ± 11.6 in this sample of

firefighters. This number is similar to previously reported data of 35.6 ± 15.3 repetitions in firefighters (29) and once more highlights the large range of the data as both groups had standard deviations of a third or more of their respective means. In our particular group the minimum value seen of 8 repetitions would place in the "needs improvement" category according to the ACSM (43), regardless of the age of the individual. Conversely, one person was able to successfully complete 60 repetitions, far exceeding the standard for an "excellent" rating from the organization. Results from this pushup test provide additional knowledge on some of the primary "pushing" muscles of the upper-body, specifically the pectorals, triceps, and deltoids. Coupled with new data on one of main "pulling" muscles, the bicep, a greater understanding of the upper-body musculature of an active firefighter can be fostered and potentially contribute to the development of training programs and predictive testing batteries. As the results of the pushup test correlated well with the dynamometer determined upper-body muscle peak torque, it is possible that the more accessible ACSM pushup test (43) may be used as a reasonably accurate assessment of upper-body strength in a firefighter population.

Core and postural muscles that support the torso were assessed for muscular endurance using the 60° abdominal endurance test and Biering-Sorensen test, respectively. Performance in the abdominal endurance test averaged 153.8 ± 94.2 s with a very large range of data, from as low as 64 s to 407 s. This may be the reason for its non-parametric distribution as it is positively skewed due to a few values that are much larger than the others and leptokurtic as most data points reside close to the mean. This group of firefighters was able to hold the upright position in the Biering-Sorensen test for an average of 113.4 ± 48.6 s as it taxed the posterior extensor muscles, particularly those of the back. Typical adult males have been shown to hold the

extended position of the Biering-Sorensen test for 146 ± 51 s and the flexed position of the 60°

abdominal endurance test for 144 ± 76 s (47). It has previously been reported that males who

experienced low-back pain in the year following testing were not able to hold the Biering-

Sorensen test position for as long as males who did not experience any low-back pain (176 s vs.

198 s, p = 0.029) (48). In addition, it has been suggested that maintaining a near 1.0 ratio

between torso flexor and extensor muscle endurance time may be ideal for optimal health (47).

There was quite a large spread of data in our firefighters' Biering-Sorensen test time, as shown

by the large standard deviation, suggesting that further research is needed with a larger sample

size in order to more accurately assess the health of firefighters' back extensor musculature as

their test results were much lower than previously reported data, even in those who eventually

experienced low-back pain. This is the first time data for either of these tests has been reported in

the firefighter population and gives insight to the health of their torso, and specifically spine

stabilizing musculature, which are being increasingly implicated in injury risk and low-back pain

(47,48). Nevertheless, it appears that some of our subjects may be at risk for back injury based

on the test results. Together with the Functional Movement Screen, these three tests may form

the basis of some type of injury-risk screening program for fire departments in the future with

additional research to better discern predictive value.

The Functional Movement Screen (FMS) aims to identify compensations in movement

patterns that may predispose an individual to an increased risk of injury (39,40). Lower scores

indicate that one has compensations in their movement patterns, which can lead to muscle

imbalances and over-use injuries over time as other less-optimally designed or positioned muscle

groups must work harder to compensate for weaker muscle groups. Out of a possible 21 points

this sample of firefighters produced an average score of 15.6 ± 1.5 points. Scores of 14 or less have been shown to be associated with an increased risk of injury in professional American football players (40) and the potential for the FMS to be used in the same manner with firefighters certainly exists. Both injury history and future injury risk have been evaluated in firefighters previously using the FMS. Firefighters with a previous injury of any type were more likely to score 16 or below on the FMS (41) and firefighters who became injured during academy training scored significantly lower than those who did not (42). There were not any significant relationships demonstrated between FMS score and either of the core or postural muscle endurance tests (abdominal flexor and back extensor tests). This study adds to the limited pool of data available on active firefighters' FMS score and may eventually contribute to the design of some type of pre-joining testing battery, perhaps with abdominal flexor endurance and back extensor endurance tests, used to predict general injury risk and overall health. Information such as this would be valuable for any type of organization or workplace involving physical activity, but especially for a fire department in which the high physical demands of the profession exacerbate any pre-existing injury or health risks. As shown in Table 3, total score in the FMS had modest, negative correlations with weight, BMI, waist circumference, and body fat percentage. Generally speaking, these measurements should be as low as possible (within a healthy range) for optimal health and that the FMS score correlates negatively with them lends further evidence to its possible use as a predictor of general health in any type of population. As more data becomes available using this measure, its power as a predictive tool can only increase. The current data suggest that there is a small sub-population of firefighters tested that may be more susceptible to on-the-job injury.

Body fat percentage has the potential to be a general predictor of health and performance in this population due to its positive correlations with many of the health-related measures and negative correlations with many of the performance tests, as shown in Table 2. The application of the present study is two-fold: to determine simple tests that can predict performance and to determine fitness variables that can serve as risk factors for on-the-job mortality. Body fat percentage addresses both of these applications as increased body fat impaired performance in almost all of the tests conducted and likely reflects an increased risk for a myocardial infarction if it is assumed to positively correlate with increased blood lipids (17). With an average of $24.2 \pm 5.4\%$ body fat, this group of firefighters did not test as well firefighter recruits ($21.8 \pm 6.2\%$), but this is to be expected somewhat as our sample was older and fitness declines with age while body fat increases (29). However, other active experienced firefighters aged 44.9 ± 4.7 years have been reported to possess $17.7 \pm 5.4\%$ body fat (19). Normative data indicates that the average 40-49 year old male has 21.9% body fat (43), so there is certainly room for improvement in this regard, especially taking into account that being in public safety profession that places a premium on physical fitness, firefighters should be expected to be leaner than their average counterpart in the population.

Body mass index (BMI) has been calculated previously in active firefighters and it was found that almost 90% were either overweight or obese by classification standards (healthy range: $18.5 - 24.9$ kg/m^2) (17). The firefighters from the current study averaged 27.8 ± 3.6 kg/m^2, putting them in the "overweight" classification (43). Interestingly, BMI has been used to predict body fat percentage by Gallagher et al. (2000) and for BMIs of $25 - 29.9$ kg/m^2 the predicted body fat is $22 - 27\%$ for males, a range encompassing our group's result (69).

Although BMI has been critiqued in the past for not differentiating between fat and fat-free mass, it has displayed a positive correlation with blood markers of cardiovascular risk in the firefighter population (17).

Waist circumference was measured in addition to calculating body fat percentage in order to gain a better understanding of not only how much fat mass one possesses, but also its distribution, as this has been increasingly implicated in increased health risks (43). Android distribution of fat (around the trunk and abdominal region) carries with it an increased risk of health problems such as hypertension, dyslipidemia, and coronary artery disease compared to a gynoid (around the hip and thigh) fat distribution (70). The current sample of firefighters possessed an average waist circumference of 93.5 ± 10.1 cm, placing them in the "low risk" category according to Bray (2004) (71). Data from reference adult men aged 42.1 ± 8.7 years indicated that their waist circumference was 97.1 ± 12.4 cm (56). The firefighters tested had a smaller waist circumference than this group from the average population, but both still are at a "low risk" of health complications (71).

The Canadian Society for Exercise Physiology (CSEP) pulled together the underlying measurements for body fat percentage, BMI, and waist circumference to produce one statistic to assess body composition and give an indication of overall health: the Canadian Physical Activity, Fitness, and Lifestyle Appraisal (CPAFLA) Healthy Body Composition Score (59). Providing new data not previously reported in this population, our firefighters achieved 7.6 ± 6.8 points out of a possible 15. Not every integer from 0-15 is a possible CPAFLA Score based on how it is calculated, thus partly explaining the large standard deviation found, relative to the mean. However, examining the range shows that both ends of the spectrum were seen with multiple

scores of both 0 and 15. Taking into account that the CPAFLA Score attempts to sum body composition variables, we see an emerging trend of a wide range of body composition levels, just as was seen with many of the performance variables. While there are many firefighters that appear to be maintaining good body composition levels, there seems to be a small portion of the sample that is not.

Some basic resting cardiovascular measures that were taken include heart rate, systolic, and diastolic blood pressure. Heart rate at rest was found to be 57.7 ± 8.2 bpm while systolic blood pressure was 121.5 ± 11.9 mm Hg and diastolic pressure was 71.5 ± 9.8 mm Hg. These data are within a normal, healthy range previously reported in $30 - 49$ year old males of 65 ± 10 bpm for resting heart rate and systolic and diastolic blood pressures of 123 ± 9 mm Hg and 76 ± 6 mm Hg, respectively (72). Previous research using male firefighters aged 40.3 ± 7.4 years has found their resting heart rate to be 67.6 ± 11.1 bpm while systolic and diastolic blood pressures were 122.7 ± 11.7 mm Hg and 77.8 ± 8.8 mm Hg, respectively (17). The present study will add further confirmatory data regarding these measures in active firefighters that may eventually be used to establish recommended guidelines for resting cardiovascular-related measures in new firefighter recruits.

5.1 Conclusion

One of the common trends that emerged from the current study is the wide range of data for many of the measures collected. In many instances this sample of firefighters' mean values were close to either pre-established standards, such as with VO_2 max, or normative population data, such as with body fat percentage. This means that probably close to half of the firefighter population falls below the standard or reference adult men in many of the fitness tasks. When

one considers that part of the duties of firefighters includes rescuing others and that there is a large physical fitness component to their profession, it should be expected that as a group their average would greatly exceed normative data so that even the least fit firefighter in the department possesses greater fitness than the average adult in the population. This is certainly cause for concern as firefighters are encouraged to maintain their fitness throughout their careers but are not subject to any formal fitness testing, save for the CPAT at the time of joining the fire department. It is unclear what proportion of firefighters exercise regularly throughout their careers but without the impetus of formal fitness testing or formal training programs, it is likely that many firefighters do not exercise sufficiently to maintain fitness at levels needed to optimally perform their jobs.

5.2 Limitations

The primary limitation of this study was the low participation and specifically, completion rate of testing. Though 49 firefighters signed up for and completed the first session of testing, only 23 actually completed all three testing sessions. Since only 47% of the sample finished the study there are legitimate concerns regarding sampling bias as participation was voluntary and thus a convenience sample was used rather than a more robust random sample. As this was a voluntary study examining physical fitness it would not be without merit to believe that those who exercise regularly and maintain their fitness would be more likely to participate and thus we may actually have experienced an over-representation of more fit people in our sample. The implication of this possibility is that the fitness of the group as a whole may actually be over-estimated. As there is already some cause for concern due to the lower-end ranges of some of the data previously discussed, this only further heightens the notion that there is

probably a small, but significant, portion of the firefighter population that does not possess the requisite physical fitness needed to optimally perform the job responsibilities expected of them. Had the entire sample completed the study, statistical significance may have been achieved in some of the measures for which there was a trend, such as the association of age with declining VO_2 max and Wingate test peak power values. In addition, this would have allowed for more sub-analysis by age and potentially uncovered trends not previously seen. Lastly, in terms of creating a database regarding firefighter physical fitness, the larger the sample the better as accuracy increases in proportion to sample size.

Another limitation of the current study was the lack of females in the sample group. Only two females were recruited to participate and only one of them was able to fully complete the study. It would have been interesting to perform sub-analysis by gender to determine if fitness characteristics differ between the sexes and specifically if the age-related decline in fitness is different as both males and females have to complete the CPAT under the same conditions and job responsibilities in the fire department do not differ.

Lastly, there was a lack of data regarding the current exercise level of our participants. Such data was originally envisioned to be collected in a concurrent study by another graduate student. Unfortunately, this other concurrent study could not be completed due to other complications. It would have been interesting to have this data available to determine if there is a connection between self-reported exercise level and actual exercise test performance as was performed in the current study. This information may have informed the design of training programs and helped to ascertain whether a lack of fitness seen in some individuals results from

a lack of exercise training or if training programs currently used are either inefficient or ineffective at maintaining and improving fitness.

5.3 Future Directions

Further research should be performed in this area in order to better quantify firefighter physical fitness as it plays an integral role in their profession and public safety as a whole. With a greater sample size and participation, more valuable and accurate conclusions can be made about their fitness status. This can then be used to design a simple and cost-efficient testing battery, which may be predictive of future performance and can help a fire department to optimize deployment of their employees to various situations. As previously discussed, there appears to be great potential in maximum vertical jump testing to be used in this regard but more research is needed to determine if it would actually be a reliable predictor of performance in other areas of fitness. Exercise programs to combat the age-related decline in fitness can also be more intelligently designed with a greater knowledge of the pre-existing fitness status of firefighters so that time and money can be focused on areas of weakness to bring the collective fitness level up. Not all individuals will require the same training program of course, but this can serve as a foundation upon which to start.

5.4 Recommendations for the Kitchener Fire Department

The most common trend found appears to be the wide range of data for many of the measurements taken, as previously discussed. Though many of Kitchener Fire Department's firefighters are at or above the required level of fitness for their profession, potentially up to 50% do not meet the recommended standard or are only at par with normative data, and some are significantly below average in various fitness aspects. Formal fitness testing that continues

throughout one's career as a firefighter may be part of a solution to ensure that all members of the department meet the minimum requirement. It may not be necessary to have annual fitness testing but perhaps a system could be put in place where fitness testing every 2 – 3 years is required. Since maintaining one's physical fitness is an integral component of a public safety job such as firefighting, perhaps an incentive program to encourage fitness maintenance could be initiated. There is a precedent for a program similar to this in Ontario for the police force called the Ontario Police Fitness Pin Award Program (73). As with firefighters, police officers are encouraged to maintain their fitness but are not subject to further formal fitness testing once they are accepted into the academy. Many police departments across Ontario offer incentives to their officers for voluntarily completing the Ontario Police Fitness Award as a means of encouraging their employees to maintain their physical fitness levels. A similar program could be made available for firefighters.

While more research is needed to provide conclusive evidence, the fire department may find it beneficial to invest in predictive testing for both new and experienced firefighters. The Functional Movement Screen (39) is an easy to administer test that does not require much time or money and has been shown to have a relationship with both injury history (41) and risk of future injury (42) in firefighter populations. Continuing with injury risk and prevention, the 60° abdominal endurance test and Biering-Sorensen test are both easy to administer without expensive equipment and may be used to assess the health of torso stabilizing musculature that is increasingly being linked to incidences of low-back pain (47). Body fat percentage correlated negatively with many of the performance measures and might be useful as general indicator of overall health but more intensive training is required to accurately use calipers to determine body

fat via skinfold thickness and thus may not be as favourable to the department looking for the most efficient solution as possible. The ACSM pushup test (43) was found to be a reasonably accurate assessment of upper-body strength and could easily be administered with minimal training, time, and space. Finally, maximum vertical jump (52) is quite simple to perform with minimal equipment and was found to be a good predictor of performance in many of the more complex tests stressing lower-body strength and power, including maximum quadriceps strength, the Wingate test, and the VO_2 max test. With further research, these five tests may serve as a simple testing battery that is reasonably accurate in predicting both injury risk (FMS, 60° abdominal endurance, Biering-Sorensen) and work performance (ACSM pushup and vertical jump). It should not take more than 20 – 30 minutes per person to complete all these tests and perhaps a fire department might perform them annually, even if only to acquire baseline data as their employees age, and their fitness inevitably decreases.

Firefighters require a well-balanced approach in a training program as they can be exposed to numerous physical fitness stressors. Aerobic training is of primary importance as they must be able sustain their workload for many minutes at a time, in addition to carrying a multitude of equipment. Our study identified that there may be a small portion of their population that does not possess sufficient aerobic capacity to optimally perform their job duties and thus lends credibility to the notion that aerobic training is of primary importance in this population. Our research has also demonstrated that some firefighters may not possess the core and spine stabilizing musculature equal to that of typical healthy adult males. It would be prudent to include abdominal and back musculature training in any program for the sake of overall health and injury risk reduction. Performing the isometric contractions of both of the tests used (60°

abdominal endurance and Biering-Sorensen test) may be a sufficient stimulus for training and also serve as a useful benchmark of progress, provided they are performed diligently. Power training is also important but less so than aerobic training in our opinion as most firefighting tasks last longer than 60 seconds, the lesser of which is the primary focus of power training. In addition, power training should focus on power endurance (e.g., > 30 s sprints) rather than attaining peak power as most firefighting tasks last longer than a few minutes. In this regard, our research has shown that concerning average power produced during the Wingate test, most of the firefighters are close to the mean with only a few falling appreciably below. It would therefore be unwise to devote significant training time to anaerobic power production both because it is not as crucial to firefighting tasks, and our sample appeared to perform quite well in this regard. Lastly, this group of firefighters performed reasonably well on most of the strength and muscular endurance measures, such as pushups and vertical jump, negating the need for extensive training in this area. Training programs for firefighters should be designed with aerobic fitness as the primary goal and a secondary emphasis on improving core and back musculature health and strength as this may be an area of weakness and increased injury risk.

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7. Appendices

7.1 Recruitment Letter

Physical fitness characteristics of an active firefighter population serving an urban area

Firefighters of the Kitchener Fire Department,

      You have previously received information about upcoming voluntary Fitness and Health Testing. Physical fitness testing will be performed in the coming weeks using a variety of measures as part of a research project at Wilfrid Laurier University (WLU) under the supervision of Dr. Peter Tiidus, and in cooperation with the Kitchener Fire Department. All data gathered will be completely anonymous and any data reporting will only occur as averages of all individuals involved. Individual participants' data can also be reported confidentially to and interpreted for those individuals wishing to personally receive such information.

      Participation in all testing is completely voluntary and you may choose not to participate or to only participate in some tests. Below is a list of all tests, which will be performed over three sessions (1 at the firehall and 2 at WLU). Testing will commence with the firehall sessions, during which you will be able to sign-up for the other 2 sessions at WLU if you would like to do so. Further health-related questionnaires will also be forthcoming later in the fall.

      Please indicate if you have an interest in being tested at the firehall (or learning more about the testing) by emailing Steve Usher at steve.usher@kitchener.ca by Friday July 26, 2013. Testing will commence on August 1, 2013 at headquarters. More information will be given prior to testing and formal consent to participate will be obtained from you when you have been fully informed of all procedures. The Informed Consent Form is attached for your viewing and provides additional information on the study. Please do not hesitate to contact me if you have any questions at anto9400@mylaurier.ca.

Regards,
Michael Antolini, MSc Student
Wilfrid Laurier University

Firehalls:
- Resting heart rate and blood pressure
- Height, weight, waist circumference
- Skinfolds: bicep, tricep, hip, back, calf
- Movement patterns
- Pushups

WLU 1
- Obstacle avoidance
- Abdominal muscular endurance

- Bicep and quadriceps maximum strength
- Wingate test (30-second cycle against heavy resistance)

WLU 2

- Back muscular endurance
- Perception of low-back injury risk (visual task)
- Vertical jump
- VO_2 max test (treadmill run to exhaustion)

7.2 Follow-Up Letter

Firefighters of the Kitchener Fire Department,

You have previously received information regarding my M.Sc thesis project testing the physical fitness of firefighters. Testing will take place over 3 sessions, the latter two of which will take place at the university. Tests to be performed include:

Firehalls:
Resting heart rate and blood pressure
Height, weight, waist circumference
Skinfolds: bicep, tricep, hip, back, calf
Movement patterns
Pushups
WLU 1:
Obstacle avoidance
Abdominal muscular endurance
Bicep and quadricep maximum strength
Wingate test (30-second cycle against heavy resistance)
WLU2:
Back muscular endurance
Perception of low-back injury risk (visual task)
Vertical jump
VO2 max test (treadmill walking test)

Participation is completely optional and you may take part in the study while declining participation in one or more tests.
Thus far 34 people are completed the first session of testing at the firehalls, however I hope to have at least 50 people participating in the study (and more than that can be accommodated and appreciated). I will be coming to the firehalls to perform the first session of testing as well as invite you to sign-up for the testing sessions at Laurier. There will be multiple time slots available to sign-up for the testing at Laurier, encompassing both evenings and weekends to better suit your schedule.

In addition, the Kitchener Fire Department will randomly select one person who has completed all 3 sessions of testing to receive a 24-hour shift off with full pay.

If you have any questions or would like to participate please do not hesitate to contact me at anto9400@mylaurier.ca.

Regards,
Michael Antolini, M.Sc Student
Wilfrid Laurier University

7.3 Informed Consent Statement

INFORMED CONSENT STATEMENT

WILFRID LAURIER UNIVERSITY

<u>Physical fitness characteristics of an active firefighter population serving an urban area</u>

Dr. Michael Cinelli, Dr. Diane Gregory, and Michael Antolini, Principle Investigators
under the supervision of Dr. Peter Tiidus
Dr. Pam Bryden, Dr. Kim Dawson, Dr. Paula Fletcher, Dr. Renee MacPhee, Zach Weston, and Meghan Hoefs, Co-Investigators

You are invited to participate in a research study. The purpose this study is to determine physical fitness characteristics of a firefighter population serving an urban area. Firefighters will be tested at both the firehalls and in two visits to Wilfrid Laurier University (WLU). Testing will include a variety of physiological baseline and maximum performance tests as well as testing to evaluate cognitive ability for obstacle avoidance in both a rested and fatigued state. This study is being conducted by Michael Antolini, a M.Sc candidate, under the supervision of Dr. Peter Tiidus (ptiidus@wlu.ca), a professor in the Department of Kinesiology and Physical Education at Wilfrid Laurier University.

<u>INFORMATION</u>
This study will assess various physical fitness and anthropometric variables in firefighters as well as cognitive ability of obstacle avoidance in both a rested and fatigued state. A health and fitness questionnaire will also be part of the study and will be distributed in due course. Data from the questionnaire and physical fitness testing may be coded by date of birth and gender so that results between the two can be linked for analysis.

There will be 3 separate testing times:
Session 1 – Firehalls: You will be outfitted with the Tango+ device and told to sit quietly in a room for 5 minutes in order to relax, after which three measurements of resting heart rate and blood pressure will be taken. Height and weight measurements will then be taken in light clothing without footwear. Your waist circumference and bicep, tricep, subscapular, iliac crest, and medial calf skinfolds will be measured. You will then perform the Functional Movement Screen, consisting of seven assessments. The assessments are the deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability pushup, and rotational stability. In the last test for the first session you will be asked to complete as many consecutive pushups as possible with proper form.

Session 2 – WLU 1: You will first report to Dr. Cinelli for an obstacle avoidance task as part of a separate research project. You will be required to walk between two obstacles for approximately 36 trials during which the distance between the obstacles will vary. In total this task will take approximately 20 minutes and you may take breaks as needed. You will be recorded using a video camera from the posterior view during this task. For the 60-degree abdominal endurance test, you will be seated on a table with your back resting on a board at a 60-degree angle. The board will be removed and you will be instructed to maintain this position for as long as possible. After a familiarization period with the equipment, you will be asked to perform three maximum strength contractions of the bicep and quadricep of your dominant limb on the CYBEX machine. After warming up on a stationary bike you will be instructed to achieve maximum pedaling speed before hitting a switch that will engage a weight basket for resistance and the 30-second

<div align="right">_____
Participant's initials</div>

Wingate test will commence. After the test you will perform a cool down on the bike and monitored to ensure no ill symptoms emerge before being directed back to Dr. Cinelli to perform his obstacle avoidance task a second time in a fatigued state.

Session 3 – WLU 2: You will first be asked to lie face-down on a table with your legs secured and upper body hanging off the edge before contracting your back extensors to bring your torso in line with your legs and hold this position for as long as possible. You will then be given a 10-minute rest period, during which you will be asked to view 10 different pictures of various tasks and postures. You will be asked to assign a numerical value to each picture in terms of your perceived level of risk of low back injury for each picture. After your standing reach height is measured you will have three attempts to jump as high as possible from a two-legged stand-still and touch a vane on the Vertec apparatus. You will be fitted with a mask to measure gas composition for a VO_2 max test and be allowed to warm up on the treadmill before being instructed to run to exhaustion with the speed and/or grade increased every 2 minutes until voluntary test termination.

Testing will require about 60 minutes at the firehall, 90-120 minutes for the first visit to WLU, and 60-65 minutes for the second session at WLU. Between 50 and 60 participants will be recruited for the study.

RISKS
The possibility exists for residual muscle soreness after some of the maximal effort tests that will be conducted. Following the pushup, abdominal, and back extensor endurance tests you may experience muscle soreness in the chest/arms, abdominals, and lower back, respectively. This should reside within a day or two and would not be any more uncomfortable than the discomfort felt following a more vigorous workout. The Wingate and VO_2 max tests are the most physically demanding and carry with them the greatest risk for minor muscle damage and soreness. A very minor risk factor with any type of maximal effort muscular test is that damaged muscle can leak proteins that can compromise kidney function in a very small group of susceptible individuals in a condition called rhabdomyolysis. During the VO_2 max you may become so exhausted that you may fall off the back of the treadmill as the speed is increased. As the participant pool is comprised entirely of firefighters of the Kitchener Fire Department a very minor theoretical possibility exists that you may become alienated from those who choose not to participate, and vice-versa. This may affect your social relationships and reputation within the workplace. Although all test results are de-identified and only presented in aggregate, you may become uncomfortable or lose self-confidence after a poor test result. In addition, the measurement of body fat percentage via the use of calipers and skinfolds may make you uncomfortable with the researcher touching your body. Please contact the researcher if you experience anything more than minor short-term muscle soreness. You will be directed to a health care professional if symptoms persist or become aggravated.

BENEFITS
This research will attempt to provide a more complete assessment of current firefighters' physical fitness using a sample that will be representative of the entire fire department. In addition, a variety of testing will be done that incorporates measures of anthropometry, cardiovascular fitness, muscular strength, endurance, and power. You will also gain an understanding of the scientific experimental process and become familiarized with different types of exercise testing procedures and apparatus.

CONFIDENTIALITY
All data will be de-identified and coded by number. Data will be reported as aggregate in any publications and no individual subjects will be identified. Hard copies of data will be stored in a locked cabinet and

_____
Participant's initials

electronic data will be stored on a password-protected computer. The principle and co-investigators, as well as Dr. Tiidus will have access to the data which will be retained until all appropriate analysis and manuscripts for publication have been completed. This may take up to five years and several analyses

may be performed using the data collected. Dr. Tiidus will ultimately be responsible for the disposal of the data.

COMPENSATION
For participating in this study you will be offered feedback and information on all of your personal test results, if desired. If you would like to receive your test results please indicate by initialing below.
Yes, I would like to receive my testing results. _____ Email address: _____
If you withdraw from the study prior to its completion, you are still eligible to receive results for tests completed thus far.

CONTACT
If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study) you may contact the researcher, Michael Antolini at Wilfrid Laurier University, Department of Kinesiology and Physical Education, or at anto9400@maylaurier.ca. This project has been reviewed and approved by the University Research Ethics Board. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Robert Basso, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-1970, ext. 4994, or at rbasso@wlu.ca.

PARTICIPATION
Your participation in this study is completely voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed. You have the right to omit any question(s)/procedure(s) you choose.

FEEBACK AND PUBLICATION
If you would like to see the findings of the research, a copy of the final paper, as it would appear in a journal, will be emailed to you free of charge. If you would like a copy of the final paper please indicate so by writing your email address below.
Yes, I would like a copy of the final paper emailed to me. Email address: _____

CONSENT
I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's name: _____

Participant's signature: _____   Date: _____

Investigator's signature: _____   Date: _____

7.4 Screening Form

SCREENING FORM

WILFRID LAURIER UNIVERSITY

Physical fitness characteristics of an active firefighter population serving an urban area

Dr. Michael Cinelli, Dr. Diane Gregory, and Michael Antolini, Principle Investigators
under the supervision of Dr. Peter Tiidus
Dr. Pam Bryden, Dr. Kim Dawson, Dr. Paula Fletcher, Dr. Renee MacPhee, Zach Weston, and Meghan
Hoefs, Co-Investigators

You are invited to participate in a research study. The purpose this study is to determine physical fitness
characteristics of a firefighter population serving an urban area. Firefighters will be tested at both the
firehalls and in two visits to Wilfrid Laurier University (WLU). Testing will include a variety of
physiological baseline and maximum performance tests as well as testing to evaluate cognitive ability for
obstacle avoidance in both a rested and fatigued state. This study is being conducted by Michael Antolini,
a M.Sc candidate, under the supervision of Dr. Peter Tiidus (ptiidus@wlu.ca), a professor in the
Department of Kinesiology and Physical Education at Wilfrid Laurier University.

Prior to participation in this study, please complete the attached Physical Activity Readiness
Questionnaire (PAR-Q) and answer the question below.

Have you been advised by a medical professional that you should not participate in vigous physical
activity or cannot currently perform all physical demands of your job as a result of musculoskeletal (i.e.,
muscle, joint, or bone) issues? Please inital next to the appropriate response.

Yes _____   *No* _____

I have read and understand the above information. I have received a copy of this form.

Participant's name: _____

Participant's signature: _____   Date: _____

Investigator's signature: _____   Date: _____

7.5 CSEP Physical Activity Readiness Questionnaire (PAR-Q)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:
- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:
- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____   DATE_____

SIGNATURE OF PARENT _____   WITNESS _____
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

7.6 Body Density Estimation Equations

Table 5. *Linear regression equations for the estimation of body density* $\times 10^3$ (kg/m^3) *from the logarithm of the skinfold thickness: density* $= c - m \times log\ skinfold$

(a) Males

Skinfold		Age (years)					
		17–19	20–29	30–39	40–49	50+	17–72
Biceps	c	1·1066	1·1015	1·0781	1·0829	1·0833	1·0997
	m	0·0686	0·0616	0·0396	0·0508	0·0617	0·0659
Triceps	c	1·1252	1·1131	1·0834	1·1041	1·1027	1·1143
	m	0·0625	0·0530	0·0361	0·0609	0·0662	0·0618
Subscapular	c	1·1312	1·1360	1·0978	1·1246	1·1334	1·1369
	m	0·0670	0·0700	0·0416	0·0686	0·0760	0·0741
Supra-iliac	c	1·1092	1·1117	1·1047	1·1029	1·1193	1·1171
	m	0·0420	0·0431	0·0432	0·0483	0·0652	0·0530
Biceps + triceps	c	1·1423	1·1307	1·0995	1·1174	1·1185	1·1356
	m	0·0687	0·0603	0·0431	0·0614	0·0683	0·0700
Biceps + subscapular	c	1·1457	1·1469	1·0753	1·1341	1·1427	1·1498
	m	0·0707	0·0709	0·0445	0·0680	0·0762	0·0759
Biceps + supra-iliac	c	1·1247	1·1259	1·1174	1·1171	1·1307	1·1331
	m	0·0501	0·0502	0·0486	0·0539	0·0678	0·0601
Triceps + subscapular	c	1·1561	1·1525	1·1165	1·1519	1·1527	1·1625
	m	0·0711	0·0687	0·0484	0·0771	0·0793	0·0797
Triceps + supra-iliac	c	1·1370	1·1362	1·1273	1·1383	1·1415	1·1463
	m	0·0545	0·0538	0·0531	0·0660	0·0718	0·0656
Subscapular + supra-iliac	c	1·1374	1·1429	1·1260	1·1392	1·1582	1·1522
	m	0·0544	0·0573	0·0497	0·0633	0·0771	0·0671
Biceps + triceps + subscapular	c	1·1643	1·1593	1·1213	1·1530	1·1569	1·1689
	m	0·0727	0·0694	0·0487	0·0730	0·0780	0·0793
Biceps + triceps + supra-iliac	c	1·1466	1·1451	1·1332	1·1422	1·1473	1·1556
	m	0·0584	0·0572	0·0542	0·0647	0·0718	0·0683
Biceps + subscapular + supra-iliac	c	1·1469	1·1508	1·1315	1·1452	1·1626	1·1605
	m	0·0583	0·0599	0·0510	0·0640	0·0768	0·0694
Triceps + subscapular + supra-iliac	c	1·1555	1·1575	1·1393	1·1604	1·1689	1·1704
	m	0·0607	0·0617	0·0544	0·0716	0·0787	0·0731
All four skinfolds	c	1·1620	1·1631	1·1422	1·1620	1·1715	1·1765
	m	0·0630	0·0632	0·0544	0·0700	0·0779	0·0744

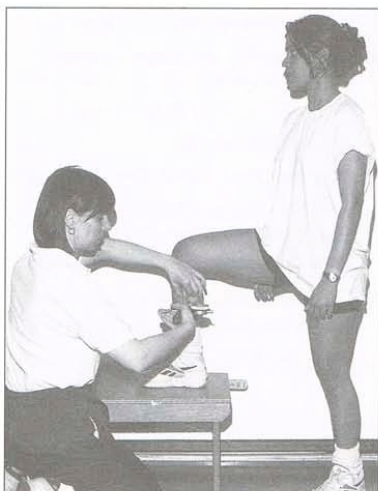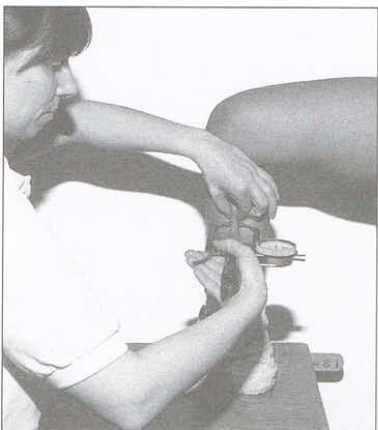## 7.7 CPAFLA Healthy Body Composition Score Criteria

Illustration 19

Illustration 20

■ INTERPRETATION AND GUIDANCE

When all the measurements have been taken, you can use these indicators for a comprehensive assessment of body composition. The indicators are:

■ *BMI – Body Mass Index:* the ratio of body weight divided by height squared (kg/m^2).

Example: Weight = 77.3 kg
Height = 171.5 cm = 1.72 m

$$BMI = \frac{77.3}{(1.72)^2} = \frac{77.3}{2.96} = 26.1$$

■ *SO5S – Sum of (five) Skinfolds (mm):* triceps, biceps, subscapular, iliac crest, and medial calf.

Example: Add triceps (12.2) plus biceps (10.2) plus subscapular (24.0) plus iliac crest (19.0) plus medial calf (14.2) = 79.6 mm

■ *Waist (Abdomen) Girth –* Simple recording of the measurement taken (cm).

Example: 84.0 cm

■ *SO2S –* Sum of (two) Trunk Skinfolds (mm): subscapular and iliac crest.

Example: Add subscapular (24.0) plus iliac crest (19.0) = 43 mm

Health Benefit Zones

Once these calculations have been made, it's a simple three-step process to determine where the clients' results fall within the health benefit zones and interpret this information for them.

Step 1: Establish healthy/unhealthy rating for each indicator.

■ Use Figure 7-4. Select the appropriate age-group table.

■ Using the proper gender columns, locate the result on the scale for each indicator (i.e., BMI, SO5S, WG, and SO2S).

■ Determine for each indicator whether it falls within the *healthy* or *unhealthy* range. (The healthy range is shaded.)

■ Record each as healthy (H) or unhealthy (UH) in the appropriate places on the Client Information Sheet.

Step 2: Establish a point score/ health benefit rating.

■ Use Figure 7-5.

■ Combine the results for BMI and SO5S as shown in the left side of the top table to establish a point score.

■ Combine the results for WG and SO2S (right, top table) to establish a second point score.

■ Add the two point scores together and use the bottom table to place clients in the appropriate health benefit zone.

■ Record points/health benefit rating on the Client Information Sheet.

Step 3: Interpret results/provide guidance.

■ Use Figure 7-6, the clients' Personal Health Benefit Ratings Summary (Tool #15) or their *Personal Plan for Active Living* booklet.

■ State the rating (Good, Very Good, etc.) achieved and the corresponding description to inform clients of their body composition status.

■ Use this information as a guide when discussing desired changes, activity goals, action steps, etc.

FIGURE 7-4	HEALTH BENEFIT ZONES BY AGE AND GENDER

for Body Weight, Adiposity and Fat Distribution Measures*

Age (yrs)   15 – 19

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	18	17	25	36	67	61	11	13
	19	18	27	40	68	63	12	14
	19	19	28	43	64	64	13	16
	20	19	29	46	70	65	13	17
	20	19	31	49	72	65	14	18
	20	20	32	51	72	66	15	19
	21	20	33	54	73	67	15	20
	21	20	35	56	74	67	16	21
	21	21	36	58	75	68	17	22
	22	21	38	61	76	68	17	23
	22	22	40	63	77	69	18	24
	22	22	42	66	78	70	19	26
	22	22	44	69	79	70	21	27
	23	23	47	72	80	71	22	29
	23	23	51	77	81	72	24	31
	24	24	54	83	82	72	27	33
	25	25	61	89	84	74	28	37
	26	26	69	97	88	77	32	42
	28	28	82	116	95	81	42	49

Age (yrs)   20 – 29

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	19	18	26	37	71	61	13	13
	20	18	29	40	73	63	14	14
	21	19	30	43	75	64	16	16
	21	19	32	46	76	65	17	17
	22	20	34	49	77	65	18	18
	22	20	36	51	78	66	19	19
	22	20	38	53	79	66	20	20
	23	21	40	56	80	67	21	21
	23	21	43	58	81	68	23	22
	23	21	46	60	82	69	25	23
	24	22	49	63	83	70	27	24
	24	22	52	65	84	71	28	26
	25	22	55	69	85	72	30	27
	25	23	58	72	86	73	32	29
	26	23	62	76	87	75	35	31
	27	24	68	81	89	77	38	33
	27	25	74	86	91	78	41	36
	28	26	82	95	93	81	46	42
	30	28	94	111	97	86	54	48

*Based on data from the Canada Fitness Survey, 1981

**BMI: Body Mass Index = Body Weight (kg) ÷ Height^2(m)

SO5S: Sum of (five) Skinfolds (mm) = Triceps + Biceps + Subscapular + Iliac Crest + Medial Calf

WG: Waist Girth (cm)

SO2S: Sum of (two) Trunk Skinfolds (mm) = Subscapular + Iliac Crest

Estimated health benefit zones according to trends in morbidity and mortality data

THE CANADIAN PHYSICAL ACTIVITY, FITNESS AND LIFESTYLE APPRAISAL   **7-19**

FIGURE 7-4 — HEALTH BENEFIT ZONES BY AGE AND GENDER
for Body Weight, Adiposity and Fat Distribution Measures*

Age (yrs) 30 – 39

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	20	19	28	40	75	63	14	14
	21	19	32	45	77	64	17	15
	22	20	35	48	79	65	19	17
	22	20	38	52	80	66	20	18
	23	21	41	55	81	68	22	20
	23	21	44	58	82	69	24	21
	24	22	46	61	83	70	26	23
	24	22	49	63	83	71	27	24
	24	22	52	66	85	72	29	25
	25	23	55	69	86	73	31	27
	25	23	58	72	87	74	33	28
	26	23	60	76	88	75	35	30
	26	24	63	79	89	76	37	32
	27	24	67	83	90	77	39	34
	28	25	71	88	92	79	42	36
	28	26	76	93	94	81	45	39
	29	27	82	99	96	83	48	43
	30	29	89	109	99	86	53	48
	32	31	101	128	106	91	59	59

Age (yrs) 40 – 49

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	21	19	28	42	78	65	15	14
	22	20	37	48	80	67	20	16
	23	20	40	51	82	68	22	18
	23	21	44	56	84	69	24	20
	24	21	46	59	85	70	26	21
	24	22	48	62	86	72	27	23
	25	22	51	66	87	73	29	25
	25	23	53	69	88	74	31	26
	25	23	56	73	89	75	32	28
	26	24	58	77	91	76	34	29
	26	24	60	81	92	77	35	32
	27	25	63	86	93	78	36	34
	27	25	66	90	94	80	38	37
	28	26	69	94	96	81	40	40
	28	27	72	98	98	83	42	43
	29	28	75	105	100	85	44	46
	30	29	79	113	102	88	47	50
	31	31	86	125	105	92	50	56
	32	34	97	150	114	99	56	65

*Based on data from the Canada Fitness Survey, 1981

**BMI: Body Mass Index = Body Weight (kg) ÷ Height^2(m)

SO5S: Sum of (five) Skinfolds (mm) = Triceps + Biceps + Subscapular + Iliac Crest + Medial Calf

WG: Waist Girth (cm)

SO2S: Sum of (two) Trunk Skinfolds (mm) = Subscapular + Iliac Crest

Estimated health benefit zones according to trends in morbidity and mortality data

FIGURE 7-4

HEALTH BENEFIT ZONES BY AGE AND GENDER
for Body Weight, Adiposity and Fat Distribution Measures*

Age (yrs) 50 – 59

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	21	20	31	48	83	67	17	16
	22	21	36	54	85	69	20	19
	23	22	40	60	87	71	22	22
	24	22	44	65	88	73	24	24
	24	23	46	69	89	75	26	26
	24	23	48	73	90	76	27	28
	25	23	51	75	91	78	29	29
	25	24	53	78	92	79	30	30
	25	24	55	81	93	80	32	31
	26	25	58	84	94	81	33	33
	26	25	60	87	95	83	35	35
	27	26	62	90	95	84	36	37
	27	26	65	93	96	85	38	39
	28	27	68	97	98	86	40	41
	28	28	71	101	99	88	43	44
	29	29	74	106	101	90	45	46
	30	30	77	112	103	92	47	49
	31	31	81	121	105	95	49	53
	32	34	88	138	109	103	54	60

Age (yrs) 60 – 69

**Measures	BMI		SO5S		WG		SO2S	
Gender	M	F	M	F	M	F	M	F
	21	20	33	45	82	66	17	16
	22	21	38	54	84	69	21	18
	23	22	41	61	87	73	23	22
	24	22	45	65	88	75	25	24
	25	23	48	67	91	77	27	25
	25	23	50	70	92	78	28	28
	25	24	52	72	92	79	29	29
	26	24	54	76	93	80	31	31
	26	25	56	80	94	81	32	33
	27	25	58	82	95	82	33	34
	27	26	59	85	96	83	34	36
	27	26	61	87	97	84	35	38
	28	27	63	93	99	85	37	40
	28	28	65	98	101	86	38	42
	28	28	69	100	103	88	40	44
	29	29	72	103	104	90	42	46
	30	30	76	112	105	93	45	49
	31	32	81	123	107	98	48	54
	33	34	91	139	112	103	55	60

*Based on data from the Canada Fitness Survey, 1981

**BMI: Body Mass Index = Body Weight (kg) ÷ Height^2(m)

SO5S: Sum of (five) Skinfolds (mm) = Triceps + Biceps + Subscapular + Iliac Crest + Medial Calf

WG: Waist Girth (cm)

SO2S: Sum of (two) Trunk Skinfolds (mm) = Subscapular + Iliac Crest

Estimated health benefit zones according to trends in morbidity and mortality data

Scoring of Body Composition Assessments

BMI healthy and SO5S healthy	8 points	WG healthy and SO2S healthy	7 points
BMI unhealthy and SO5S healthy	8 points	WG unhealthy and SO2S healthy	5 points
BMI healthy and SO5S unhealthy	3 points	WG healthy and SO2S unhealthy	2 points
BMI unhealthy and SO5S unhealthy	0 points	WG unhealthy and SO2S unhealthy	0 points

Corresponding Health Benefit Zones for Healthy Body Composition

15 points	Excellent
13 points	Very Good
7 – 10 points	Good
2 – 5 points	Fair
0	Needs Improvement

Health Benefit Zone

Excellent   ⇧   Your body composition falls within a range that is generally associated with optimal health benefits.

Very Good   ⇧   Your body composition falls within a range that is generally associated with considerable health benefits.

Good   ⇧   Your body composition falls within a range that is generally associated with many health benefits.

Fair   ⇧   Your body composition falls within a range that is generally associated with some health benefits but also some health risks. *Progressing from here into the GOOD zone is a very significant step to increasing the health benefits associated with your body composition.*

Needs improvement   ⇧   Your body composition falls within a range that is generally associated with considerable health risks. *Try to achieve and maintain a healthy body composition by enjoying regular physical activity and healthy eating.*

7.8 Functional Movement Screen Movement Patterns & Scoring Criteria

DEEP SQUAT
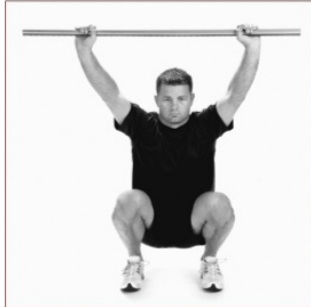
3
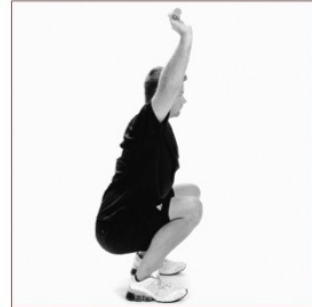
Upper torso is parallel with tibia or toward vertical | Femur below horizontal
Knees are aligned over feet | Dowel aligned over feet

2
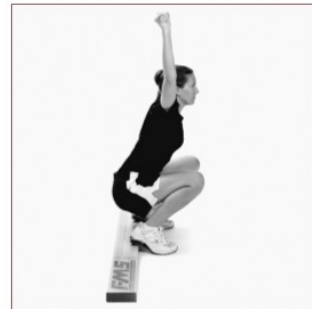
Upper torso is parallel with tibia or toward vertical | Femur is below horizontal
Knees are aligned over feet | Dowel is aligned over feet | Heels are elevated
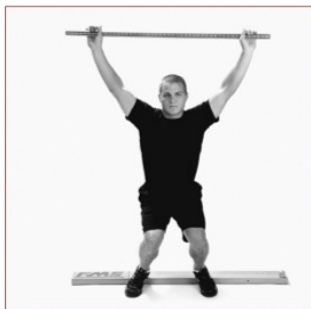
1
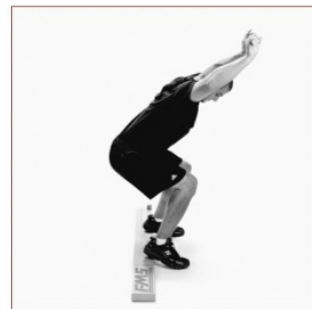
Tibia and upper torso are not parallel | Femur is not below horizontal
Knees are not aligned over feet | Lumbar flexion is noted
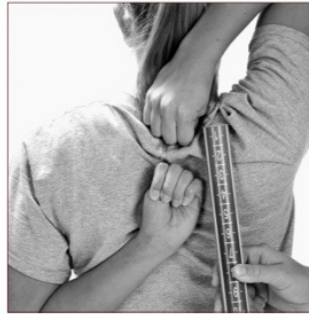
The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

3

Hips, knees and ankles remain aligned in the sagittal plane
Minimal to no movement is noted in lumbar spine | Dowel and hurdle remain parallel

2
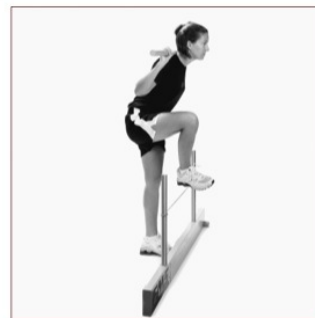
Alignment is lost between hips, knees and ankles | Movement is noted in lumbar spine
Dowel and hurdle do not remain parallel

1
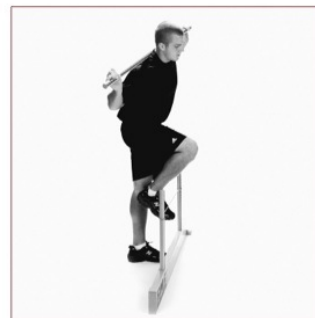
Contact between foot and hurdle occurs | Loss of balance is noted

The athlete receives a score of zero if pain is associated with any portion of this test.
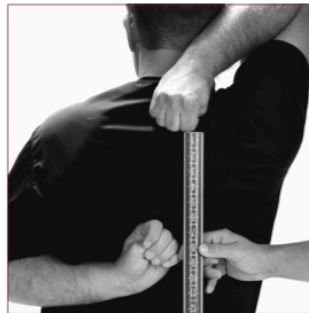A medical professional should perform a thorough evaluation of the painful area.

3
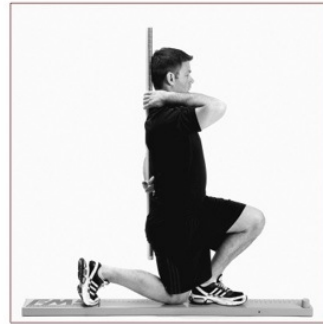
Dowel contacts maintained | Dowel remains vertical | No torso movement noted
Dowel and feet remain in sagittal plane | Knee touches board behind heel of front foot
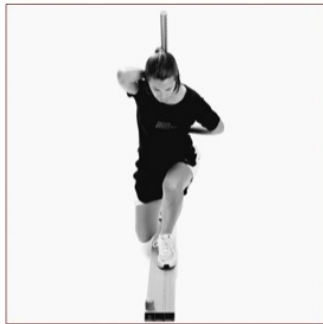
2

Dowel contacts not maintained | Dowel does not remain vertical | Movement noted in torso
Dowel and feet do not remain in sagittal plane | Knee does not touch behind heel of front foot
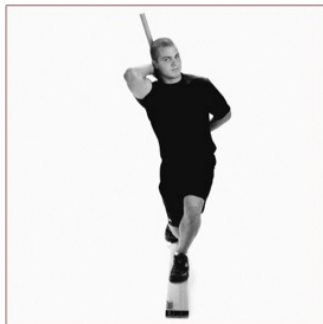
1

Loss of balance is noted

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

3

Fists are within one hand length

2

Fists are within one-and-a-half hand lengths

1

Fists are not within one and half hand lengths

The athlete will receive a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.
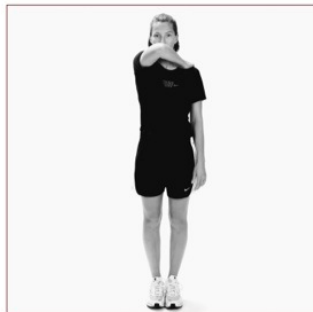
CLEARING TEST

Perform this clearing test bilaterally. If the individual does receive a positive score, document both scores for future reference. If there is pain associated with this movement, give a score of zero and perform a thorough evaluation of the shoulder or refer out.

ACTIVE STRAIGHT-LEG RAISE

3

Vertical line of the malleolus resides between mid-thigh and ASIS
The non-moving limb remains in neutral position

2

Vertical line of the malleolus resides between mid-thigh and joint line
The non-moving limb remains in neutral position

1

Vertical line of the malleolus resides below joint line
The non-moving limb remains in neutral position

The athlete will receive a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

3

The body lifts as a unit with no lag in the spine

Men perform a repetition with thumbs aligned with the top of the head
Women perform a repetition with thumbs aligned with the chin

2
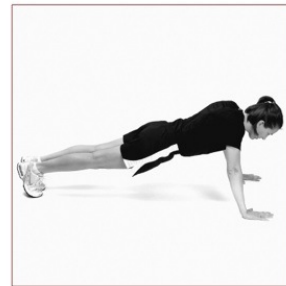
The body lifts as a unit with no lag in the spine
Men perform a repetition with thumbs aligned with the chin | Women with thumbs aligned with the clavicle

1

Men are unable to perform a repetition
with hands aligned with the chin

Women unable with thumbs aligned with the clavicle

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.
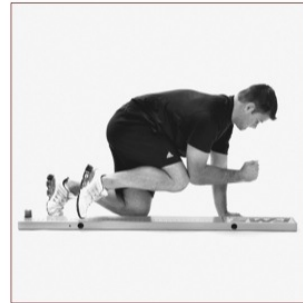
SPINAL EXTENSION CLEARING TEST

Spinal extension is cleared by performing a press-up in the pushup position. If there is pain associated with this motion, give a zero and perform a more thorough evaluation or refer out. If the individual does receive a positive score, document both scores for future reference.
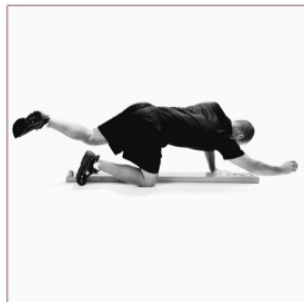
3

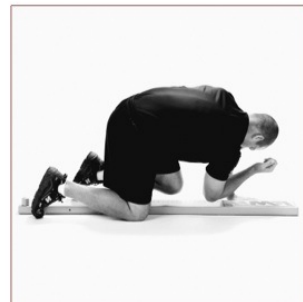Performs a correct unilateral repetition
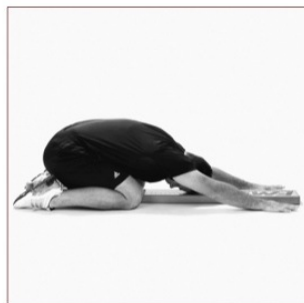

2

Performs a correct diagonal repetition

1

Inability to perform a diagonal repetition

The athlete receives a score of zero if pain is associated with any portion of this test.
A medical professional should perform a thorough evaluation of the painful area.

Spinal Flexion Clearing Test

Spinal flexion can be cleared by first assuming a quadruped position, then rocking back and touching the buttocks to the heels and the chest to the thighs. The hands should remain in front of the body, reaching out as far as possible. If there is pain associated with this motion, give a zero and perform a more thorough evaluation or refer out. If the individual receives a positive score, document both scores for future reference.

7.9 Modified Bruce Protocol for VO₂ max Treadmill Test

Stage	Time	Speed (km/h)	Grade (%)
1	00:00	4.0	0
2	02:00	4.8	0
3	04:00	5.1	2
4	05:30	5.5	4
5	07:00	5.8	6
6	08:30	6.1	8
7	10:00	6.4	10
8	11:30	6.8	12
9	13:00	7.1	14
10	14:30	8	16
11	16:00	8.8	18
12	17:30	9.7	20