JOB-RELATED AEROBIC AND MUSCULOSKELETAL FITNESS STANDARDS FOR FRONT-LINE STRUCTURAL FIREFIGHTERS THAT QUALIFY AS BONA FIDE OCCUPATIONAL REQUIREMENTS; CRITICAL CONSIDERATIONS

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ABSTRACT

Maximal oxygen consumption (VO_2max) reflects the upper limit of the body's aerobic fitness and represents the highest rate at which oxygen can be taken up, transported, and utilized by the body. It is the most widely used measure characterizing the effective integration of the body's many physiological systems in exercise sciences. However, the precise measurement administration protocol and relevance of VO_2max regarding physically demanding public safety occupations remain unclear. Structural firefighter applicants routinely have their VO_2max measured to ensure that they possess the aerobic fitness required to perform the most frequently occurring and physically demanding on-the-job tasks safely and efficiently.

The purpose of this research project was to determine 1) if using a verification phase (VP), following a graded exercise test (GXT), helped to accurately measure VO_2max and affected the proportion of participants who met the job-related aerobic fitness standard, 2) if there were any significant relationships between the firefighter applicants' VO_2max, select physical characteristics and simulated job task completion times and performance scores, and 3) what effect short-term reduced-training (i.e., detraining), consequent to the COVID-19 pandemic restrictions, had on the job-related aerobic fitness and critical simulated job task completion times of firefighter applicants.

Performing a VP helped to accurately measure VO_2max and significantly increased the proportion of participants who met the job-related aerobic fitness standard. A VP should always be used to ensure the measurement of a VO_2max and not just a VO_2peak. Participants' VO_2max and select physical characteristics had significant negative regression weights on all simulated job task completion times. Multiple regression equations can predict simulated job task completion times and allow applicants to customize their physical activity and exercise regimes to ensure that

they have the physical and physiological characteristics to successfully meet the job-related aerobic fitness and simulated job task standards.

Short-term periods of reduced training significantly decreased the participants' ability to meet the job-related aerobic fitness standard. Structural firefighters must engage in habitual exercise regimes to ensure they possess the aerobic and musculoskeletal fitness required to perform critical on-the-job tasks safely and efficiently during emergencies where job completion is critical to safety, life, and property.

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LIST OF ACRONYMS

a-vO_2diff	Arterial and venous oxygen difference
BFOR	Bona fide occupational requirement
BMI	Body mass index
BV	Blood volume
CAF	Canadian Armed Forces
CO_2	Carbon dioxide
CRF	Cardiorespiratory fitness
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DFR	Diastolic filling rate
dp	Aortic pressure
dt	Diastolic filling time
EDV	End-diastolic volume
ESV	End-systolic volume
FORCE	Fitness for Operational Requirements of Canadian Armed Forces Employment
F_EO_2	Fraction of oxygen in expired air
F_IO_2	Fraction of oxygen in inspired air
GXT	Graded exercise test
Hb	Hemoglobin
HR	Heart rate
HRmax	Maximal heart rate
LV	Left ventricle
LVER	Left ventricular emptying rate

MAP	Mean arteriole pressure
O_2	Oxygen
PAR-Q+	Physical Activity Readiness Questionnaire for Everyone
PEP	Pre-ejection period
PPE	Personal protective equipment
PVexp	Plasma volume expansion
Q	Cardiac output
Qmax	Maximal cardiac output
RER	Respiratory exchange ratio
SBP	Systolic blood pressure
SFFA	Structural Firefighter Fitness Assessment
SV	Stroke volume
SVmax	Maximal stroke volume
TPR	Total peripheral resistance
V_E	Volume of expired air
V_I	Volume of inspired air
VO_2	Oxygen consumption
VO_2max	Maximal oxygen consumption
VO_2peak	Peak oxygen consumption
VP	Verification phase

EXECUTIVE SUMMARY

Firefighting is a physically demanding public safety occupation that, under emergency circumstances, may require front-line structural firefighters to work at vigorous intensity for sustained periods (Gledhill & Jamnik, 1992). Therefore, successful job performance and individual safety depend largely on firefighters' aerobic and musculoskeletal fitness levels (Gledhill & Jamnik, 1992). As such, firefighter applicants must have their physical and physiological fitness measured using established job-related aerobic fitness and critical simulated job tests as part of a more comprehensive pre-employment Structural Firefighter Fitness Assessment (SFFA). These pre-employment fitness screening tests are intended to demonstrate the employer's due diligence in addressing potential threats to the employee and public safety plus property, and therefore, are scientifically established to *qualify* as a Bona Fide Occupational Requirement (BFOR) (Gledhill & Jamnik 1992; Jamnik et al., 2010a, Jamnik et al., 2010b; Gumienak, Jamnik & Gledhill, 2013).

Aerobic fitness is assessed by estimating or directly measuring an individual's maximum oxygen consumption (VO_2max). VO_2max is "the oxygen uptake during exercise intensity at which actual oxygen intake reaches a maximum beyond which no increase in effort can raise it" (Hill & Lupton, 1923). It is a quantifiable and reproducible measurement of the cardiorespiratory system's ability to maximally uptake, deliver and use oxygen during incremental to maximal intensity exercise (Hawkins et al., 2007). VO_2max is estimated or directly measured using submaximal or maximal aerobic fitness tests. It is most commonly and accurately measured during incremental to maximal graded exercise tests (GXT) using indirect calorimetry via open-circuit spirometry. Research suggests firefighters should develop and maintain a VO_2max of at least 42.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (Storer et al., 2014). This minimum job-related aerobic fitness standard allows for a 5%

reserve capacity that offers firefighters a margin of safety when performing critical, physically demanding, and frequently occurring on-the-job tasks (Gledhill & Jamnik, 1992). Possessing an even higher VO_2max of 45.0 to 50.0 $mL \cdot kg^{-1} \cdot min^{-1}$ provides an incremental reserve capacity of 10-20%, which ensures that the front-line firefighters are physically capable of performing the critical physically demanding tasks safely and efficiently during emergencies (Smith, 2011).

Critical work-related job tests are commonly used to measure musculoskeletal mobility, flexibility, power, strength, and endurance. These job tests usually include several tasks designed to simulate the physical demands of the actual on-the-job emergency tasks (e.g., hose carry, rope pull, hose advance, ladder lift, victim drag and forced entry). Firefighter applicants must meet the SFFA completion time standards for each critical job task to prove that they can safely and efficiently perform the most physically demanding and frequently occurring on-the-job tasks.

MANUSCRIPT I

Firefighter applicants routinely have their aerobic fitness measured to ensure they meet the SFFA job-related aerobic fitness standard. VO_2max is most accurately measured using incremental to maximal GXT using indirect calorimetry and direct gas analysis. During the continuous GXT, ventilation measurement devices (e.g. Tissot gasometers, Douglas bags, pneumotachometers, flow meters, etc.) are used to collect inspired and expired air volumes, while rapid response gas analyzers are used to measure fractional concentrations of O_2 and CO_2, in the atmosphere and expired air. These test variables are then used to calculate VO_2max using the Haldane transformation equation ($VO_2 = (V_I \times F_IO_2) - (V_E \times F_EO_2)$), where F_IO_2 is the fraction of O_2 in inspired air, F_EO_2 is the fraction of O_2 in expired air, V_I is the volume of inspired air and V_E is the volume of expired air.

During the GXT, primary and secondary criteria are generally used to confirm the attainment of a VO_2max. The achievement of a VO_2 plateau (e.g., changes ≤ 150 $mL \cdot min^{-1}$ or 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ between two consecutive stages despite an increase in exercise intensity) is the primary criterion used to confirm the attainment of a "true" VO_2max (Bassett & Howley, 2000; Taylor, Buskirk & Henschel, 1955). However, since VO_2 plateaus are not always attained in all tested individuals when performing an incremental to maximal GXT, several secondary criteria are commonly applied; a respiratory exchange ratio (RER) of 1.00 – 1.15, a blood lactate concentration of ≥8 $mMol \cdot L^{-1}$ and a heart rate (HR) > 90% of age-predicted HRmax (Howley, Bassett & Welch, 1995). However, these criteria are often inconsistent and have great inter-subject variability, compromising their sensitivity and reliability (Poole & Jones, 2017). Furthermore, the number of criteria used to determine VO_2max is often contingent on the preference of the researcher or clinician administering the GXT. This often results in erroneously accepting a VO_2peak as a VO_2max. Although VO_2peak and VO_2max are often used synonymously in the literature, the two are not the same. VO_2peak is the highest VO_2 value measured during incremental to maximal intensity exercise performed to volitional fatigue, while VO_2max is the highest physiological attainable value (Day et al., 2003). Interestingly, a VO_2peak is not always maximal, but a VO_2max is always a peak. Consequently, a viable alternative must be identified to confirm the attainment of a VO_2max and not just VO_2peak.

Therefore, a verification phase (VP) used immediately after an incremental to maximal GXT performed to volitional fatigue has been proposed as the new "gold standard" protocol for the measurement of VO_2max (Thoden, MacDougall & Wilson, 1991). The VP consists of one or more 2-minute supramaximal intensity workloads (i.e., an intensity greater than the previous workload) separated by one or more 2-minute rest periods until a VO_2 plateau confirms the attainment of a VO_2max. This is especially important for non-athletes (i.e., firefighter applicants) who may not possess the work tolerance required to exercise continuously for long enough to sufficiently tax the body's cardiovascular system and reach an actual VO_2max during the incremental to maximal GXT.

The purpose of this study was to 1) determine if there were significant differences between the VO_2peak values measured during the incremental to maximal GXT and the VO_2max values measured during the VP, 2) determine if using a VP immediately after an incremental to maximal GXT would significantly increase the proportion of participants who meet the job-related aerobic fitness standard for structural firefighters and 3) determine if there were any significant differences in descriptive characteristics (e.g. sex, age, height, body mass, body mass index (BMI), and VO_2max) between those participants who attained their VO_2max during the GXT and those who required the VP.

4462 study participants (4179 males and 283 females) completed a GXT and, if required, a VP to measure their VO_2max. For the participants who required a VP to attain their VO_2max, their VO_2peak values measured during the GXT were compared to their VO_2max values measured during the VP. The proportion of participants who met the job-related aerobic fitness standard during the GXT was compared to that of those who met the job-related aerobic fitness standard during the VP. Only 24.6% of participants attained their VO_2max during the GXT. This means that 75.4% of participants could only reach a VO_2peak during the GXT and required the VP to attain their VO_2max. For these participants, the VO_2peak values achieved during the GXT were significantly lower than the VO_2max values reached during the VP. Because of this, the proportion of participants who met the job-related aerobic fitness standard for structural firefighters increased from 79.8% during the GXT to 92.6% during the VP, a statistically significant increase ($p < 0.001$).

This study's results indicate that most participants cannot attain their VO_2max, as confirmed by the presence of a VO_2 plateau, during an incremental to maximal GXT alone and require a VP. Therefore, firefighter applicants should complete a VP following the incremental to maximal GXT performed to volitional fatigue to accurately measure their VO_2max and not just a VO_2peak. Using a VP following an incremental to maximal GXT to volitional fatigue significantly increased the proportion of individuals who met the job-related aerobic fitness standard for structural firefighters. This is especially important for females, older individuals and overweight or obese individuals whose mean VO_2max values tend to be significantly lower compared to their counterparts and are much closer to the aerobic fitness standard for structural firefighters. The findings of this study are also applicable to any situation in which repeated measurements of VO_2max are taken to establish the efficacy of a training stimulus/physical activity intervention or the impact of pharmaceutical interventions on sport-related or occupational physiological fitness.

MANUSCRIPT II

Firefighter applicants' job-related aerobic and musculoskeletal fitness are commonly assessed using VO_2max and critical work-related job tests. The work-related job tests include several tasks designed to simulate the physical demands of the actual on-the-job tasks (e.g. hose carry, rope pull, hose advance, ladder lift, victim drag, and forced entry). Firefighter applicants must be able to complete these simulated job tasks within a given time, safely and efficiently, to be hired as front-line workers. Many studies have been published that examine the relationships between various aspects of firefighters' physical fitness and their firefighting job performance (Davis, Dotson & Santa Maria, 1982; Michaelides et al., 2008; Rhea, Alvar & Gray, 2004; Williford et al., 1999). However, these studies have failed to explore the relationships between the individual's physical and physiological characteristics and their ability to meet the time completion standards for each simulated job task as well as the overall job-related work test standard (i.e., meets the standard or does not meet the standard). A better understanding of the physical and physiological requirements of firefighting performance would enable firefighter applicants and returning-to-work incumbents to better prepare for and meet the standards required for each simulated job task and overall job-related work test.

This study examines the relationships between the participants' aerobic fitness, select physical characteristics, simulated job task completion times, and performance scores in structural firefighter applicants undergoing the SFFA. In particular, the goals of this study were to 1) determine the number and proportion of participants to complete each simulated job task and the related mean completion times, 2) determine the number and proportion of participants to meet each simulated job task performance standard and the overall job-related work test performance standard, 3) determine the sex, age, height, body mass, BMI and aerobic fitness of those participants who did and did not meet the overall job-related work test performance standard, 4) identify the relationships between select physical characteristics, aerobic fitness and individual simulated job task completion times, 5) develop logistic regression models to predict individual simulated job task performance scores based on the participants' select physical characteristics and aerobic fitness, and 6) develop equations to predict individuals' simulated job task completion times based on their select physical characteristics and aerobic fitness.

1902 (1133 male and 769 female) structural firefighter applicants completed an aerobic fitness test plus several standardized simulated job tasks as part of the more comprehensive SFFA protocol. An incremental to maximal GXT and VP, if required, were employed on a motorized treadmill to measure each participant's VO_2max. Participants were given a 10-minute rest after the aerobic fitness test before attempting the simulated job tasks. The hose carry, rope pull, hose advance, victim drag, and forced entry simulated job tasks were completed individually, and participants were required to meet SFFA completion time standards. The ladder lift simulated job task was not timed and was scored on a pass-or-fail basis. Individuals unable to complete a simulated job task successfully or whose completion time was too slow were given one re-test opportunity of that simulated job task during the testing session. The performance scores for each simulated job task (i.e., meets the standard or does not meet the standard) were based on individuals completing the simulated job tasks at a safe and efficient pace (i.e., no running was allowed). Participants were required to meet the SFFA completion time standards for each simulated job task to meet the overall job-related work test performance standard.

The physical characteristics of the study participants indicate that the male participants were significantly older, taller, and heavier than the female participants ($p < 0.001$). In addition, the male participants had significantly larger BMI and VO_2max values than the female participants ($p < 0.001$). The male participants had significantly faster completion times for each simulated job task than the female participants ($p < 0.001$). A significantly greater proportion of the male participants met each simulated job task performance standard and the overall job-related fitness test standard ($p < 0.001$). 1093 (96.5%) male participants met the overall job-related fitness test standard. In contrast, only 495 (64.4%) female participants met the overall job-related fitness test standard. Significant disadvantages in height, body mass and aerobic fitness likely affected the female participants' significantly slower completion times and lower performance scores, as performing the simulated job tasks requires aerobic and musculoskeletal fitness. Height, body mass and VO_2max had significant negative regression weights on all simulated job task completion times ($p < 0.05$). The binomial regression models correctly classified 87.4 to 95.2 percent of simulated job task performance scores based on sex, age, height, body mass and VO_2max. Finally, the multiple regression equations can predict individual simulated job task completion times based on any given set of independent variables (e.g. sex, age, height, body mass and VO_2max).

Firefighter applicants can use these equations to predict their simulated job task completion times based on their sex, age, height, body mass and VO_2max to ensure they are fully prepared for the entry-level fitness assessment. To do this, firefighter applicants must strive to find the right balance between physical characteristics, aerobic fitness training, and musculoskeletal fitness training to meet the required job-related fitness test standards and to be eligible for hire.

MANUSCRIPT III

Firefighter applicants generally undertake training or conditioning programs to ensure that they possess the aerobic and musculoskeletal fitness required to meet the job-related aerobic and musculoskeletal fitness standards and perform any emergency on-the-job tasks safely and efficiently. These training or conditioning programs should incorporate the five common training principles: overload, progression, specificity, variation, and reversibility (Viru, 1995).

It is not uncommon for firefighters applicants to experience interruptions in their training regimes for various reasons (e.g., illness, injury, pandemic, work schedules, etc.), which can lead to the partial or complete loss of training-induced performance adaptations (Fleck, 1994). This loss of performance adaptations is known as “training reversibility” and is one of the five common training principles listed above. The principle of “training reversibility” asserts that “whereas regular physical training results in several physiological adaptations, stopping or markedly reducing training results in a partial or complete reversal of these adaptations, thus compromising physical performance" (Mujika & Padilla, 2000). That is, the principle of training reversibility describes the condition of "detraining" (Hawley & Burke, 1998). Overall, the effects of detraining on the physical and physiological attributes of moderately physically active individuals or those who train to enhance job performance are less understood than those of chronically trained elite athletes.

The emergence of COVID-19 and the numerous public lockdowns associated with this pandemic provided a unique opportunity to examine the effects of short-term detraining (i.e., reduced-training lasting < 4 weeks) on the aerobic fitness and simulated job task performance of long-term moderately active or recently trained individuals. This study focuses on detraining periods lasting up to four weeks (i.e., short-term detraining) as this was the average length of time that gymnasia, fitness and recreational facilities were locked down during the various waves of the COVID-19 pandemic. Therefore, we hypothesized that the COVID-19 pandemic, and the numerous lockdowns associated with it, prevented many individuals from performing their regular training regimes and would negatively affect their aerobic and musculoskeletal fitness.

The purpose of this study was to determine what effect short-term non-bed rest detraining (i.e., reduced-training lasting < 4 weeks) had on the aerobic fitness (VO_2max) and simulated job task performance of long-term moderately active or recently trained individuals (i.e., firefighter applicants). More specifically, the objectives were to 1) determine the effect of short-term detraining on the VO_2max of structural firefighter applicants, 2) determine the effect of short-term detraining on the simulated job task completion times/performance scores of firefighter applicants, and 3) determine what effect short-term detraining had on the proportion of firefighter applicants who were able to meet the aerobic fitness standard, each simulated job task standard and the overall job-related fitness standard of the SFFA.

1718 (362 female and 1356 male) structural firefighter applicants completed an aerobic fitness test and simulated job tasks before the COVID-19 pandemic. Also, 432 (71 female and 361 male) structural firefighter applicants completed an aerobic fitness test and the same simulated job tasks during the COVID-19 pandemic (while lockdown restrictions were temporarily lifted). An incremental to maximal GXT plus VP, if required, was employed on a motorized treadmill to measure each participant's VO_2max directly. Participants were given a 10-minute rest after the aerobic fitness test before attempting the simulated job tasks. The hose carry, rope pull, hose advance, victim drag, and forced entry simulated job tasks were each completed individually, and participants were required to meet SFFA completion time standards. The ladder lift simulated job task was not timed and was scored on a pass-or-fail basis.

Participants who completed the aerobic fitness test during the COVID-19 pandemic had significantly lower VO_2max scores than those who completed the aerobic fitness test before the COVID-19 pandemic ($p < 0.001$). Overall, significantly fewer individuals met the overall firefighter fitness standard during the COVID-19 pandemic compared to before the COVID-19 pandemic ($p < 0.001$). Interestingly, similar results were not found for the simulated job tasks portion of the SFFA. The mean completion times measured during the COVID-19 pandemic were i) the same as before the COVID-19 pandemic for some simulated job tasks (e.g., the hose carry), ii) significantly faster than before the COVID-19 pandemic for some simulated job tasks (e.g., the hose advance and forced entry), and iii) significantly slower than before the COVID-19 pandemic for some simulated job tasks (e.g., the rope pull and victim drag). Similar to the findings in manuscript II, male participants had faster completion times on all simulated job tasks regardless of if they were performed before or during the COVID-19 pandemic.

This study shows that short-term reduced training, especially when customary training facilities are unavailable, has a significant adverse effect on the aerobic fitness of firefighter applicants, thereby significantly reducing their ability to meet the overall SFFA performance standards. These results support annual fitness testing for industrial athletes as breaks from or cessation of regular aerobic and musculoskeletal training programs can result in reduced performance and affect one's ability to meet the aerobic and job-related fitness standards required of structural firefighters.

CHAPTER 1: INTRODUCTION and REVIEW OF LITERATURE

FORWARD TO THE THESIS

This thesis consists of three separate manuscripts, preceded by an executive summary, introduction and literature review. The three manuscripts are followed by the limitations and implications of the research findings sections. This thesis concludes with a detailed list of references.

This thesis consists of the following three manuscripts:

I. **Performing a verification phase immediately after an incremental to maximal graded exercise test increases the proportion of participants who meet the job-related aerobic fitness standard for structural firefighters.**
Hancock R.

II. **Using firefighter applicants' aerobic fitness and select physical characteristics to predict their simulated job task completion times and performance scores.**
Hancock R.

III. **The effects of short-term detraining due to the COVID-19 Pandemic lockdowns on the aerobic fitness and simulated job task performance of firefighter applicants.**
Hancock R.

1.1. INTRODUCTION

During the 1920s, British physiologist Archibald Hill conducted a series of seminal experiments that remain the genesis of exercise physiology as an academic discipline (Hill & Lupton, 1923). Using Douglas bags to collect expired air samples, Haldane gas analyzers to determine fractional concentrations of oxygen (O_2) and carbon dioxide (CO_2), and Tissot gasometers to measure expired air volumes, he repeated running trials of increasing treadmill speed to plot the relationship between exercise intensity and oxygen consumption (VO_2). He concluded that a “ceiling” or “plateau” exists in the amount of O_2 that an individual can use during incremental to maximal intensity exercise (i.e., maximal oxygen consumption (VO_2max)). Hill and Lupton (1923) first described the term VO_2max as “the oxygen uptake during an exercise intensity at which actual oxygen intake reaches a maximum beyond which no increase in effort can raise it”. Today, the concept that the measurement of VO_2max is a quantifiable and reproducible measurement of the cardiorespiratory system’s ability to maximally uptake, deliver and utilize oxygen has been repeated sufficiently that it has achieved universal acceptance (Hawkins et al., 2007). A PubMed search for VO_2max yields more than 11,000 results and underscores the foundational importance of this concept for understanding physiological function and sport/work performance outcomes. However, although VO_2max is one of the most ubiquitous measurements in all exercise science (Levine, 2008), misconceptions still exist about its’ measurement and applications, especially when it comes to physically demanding public safety occupations (e.g., firefighting).

1.2. REVIEW OF LITERATURE

VO_2max reflects the upper limit of the body’s aerobic fitness. It is the most widely used measure characterizing the effective maximal integration of the body’s many physiological systems (e.g. central nervous system, cardiopulmonary system, metabolic system, musculoskeletal system, etc.) (Day et al., 2003).

1.2.1. Terminology

Maximal oxygen consumption (VO_2max) and peak oxygen consumption (VO_2peak) are often used interchangeably in literature to describe aerobic fitness. However, it must be noted that a difference exists between VO_2max and VO_2peak, and these terms are not synonymous. VO_2peak is the highest value attained during exercise performed to volitional fatigue and represents an individual's exercise tolerance, while VO_2max represents the highest physiological attainable value (Day et al., 2003). Interestingly, a VO_2max is always a VO_2peak, but a VO_2peak is not always maximal. In fact, the difference between VO_2peak and VO_2max is often determined by the presence of a VO_2 plateau (e.g., changes in $VO_2 \leq 150$ $mL \cdot min^{-1}$ or 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ between two consecutive workloads despite an increase in exercise intensity) (Bassett & Howley, 2000; Taylor, Buskirk & Henschel, 1955).

1.2.2. The Fick equation

VO_2max is constrained by the limitations of the Fick equation, which states that "VO_2 is equal to the product of cardiac output (Q) and the difference between arterial and venous O_2 content at the level of the capillary ($a\text{-}vO_2diff$) (Lambert, 1918).

$$VO_2(mLO_2 \cdot min^{-1}) = Q(L \cdot min^{-1}) \text{ x } a\text{-}vO_2diff(mLO_2 \cdot L^{-1})$$

This equation can be further expanded to represent Q as the product of heart rate (HR) and left ventricular (LV) stroke volume (SV), with SV being the difference between LV end-diastolic volume (EDV) and end-systolic volume (ESV) (Tipton, 2014).

$$VO_2(mLO_2 \cdot min^{-1}) = (HR(b \cdot min^{-1}) \times (EDV(mL \cdot b^{-1}) - ESV(mL \cdot b^{-1})) \times a\text{-}vO_2diff(mLO_2 \cdot mL^{-1})$$

The components of the Fick equation represent individual central (Q) and peripheral (a-vO_2diff) factors. The central part consists of the diffusion of O_2 in the lung from the external environment into the arterial blood supply and the delivery of oxygenated blood through systemic circulation to working skeletal muscle tissue. The peripheral component comprises various cellular and molecular mechanisms at the skeletal muscle level to diffuse O_2 from arterial blood to the mitochondria for consumption in ATP resynthesis (Levine, 2008). Most of our understanding of aerobic fitness is based on this equation and its variables. However, the simplicity of this equation understates all the intricacies of the body's numerous integrated systems.

1.2.3. Central factors that affect VO_2max

It is well established that Q increases at a linear rate with VO_2 throughout incremental to maximal exercise (Crisafulli et al., 2005; Faulkner et al., 1971; Lewis et al., 1983; Stringer, Hansen & Wasserman, 1997; Proctor et al., 1998). This increase in Q is a consequence of several physiological adjustments, which include increases in preload, HR, SV, systolic blood pressure (SBP), mean arteriole pressure (MAP) with essentially no change in diastolic blood pressure (DBP) along with metabolically induced vasodilation in working skeletal muscle (Lewis et al., 1983). Central medullary control of baroreceptors, chemoreceptors, and vascular tone contributes to the withdrawal of parasympathetic activity coupled with an increase in sympathetic drive in the circulatory system and an increase in chronotropic and ionotropic characteristics of the heart (Beltz et al., 2016).

Generally, HR increases linearly from rest (70 bpm) during incremental to maximal exercise (170-200 bpm). However, a HR threshold is eventually reached, after which the slope may increase or decrease until maximal HR (HRmax) is achieved. The HR threshold is a unique and individual phenomenon that may indicate chronotropic insufficiency or downregulation in beta-1 adrenergic receptor activation during greater exercise intensities (Knight-Maloney et al., 2002).

With the increasing ionotropic response, the shift to sympathetic nervous system dominance raises chronotropic activity and influences central mechanical changes with increasing exercise intensity. Because SV is affected by myocardial contractility and the Frank-Sterling mechanism, examining their relative contributions is very important.

The pre-ejection period (PEP) is when isovolumetric contraction occurs. During this diastolic filling time (dt), the pressure in the left ventricle increases rapidly from the end-diastolic pressure up to exceeding the aortic pressure (dp). This change in pressure per unit of time (dp/dt) provides a valuable index of the vigour of ventricular contraction (myocardial contractility). The alterations that occur in dp from rest through incremental to maximal exercise are quite modest relative to the corresponding alterations in dt (PEP). Hence, dp has a comparatively minor impact on dp/dt, whereas dt has a significant effect. Therefore, PEP alone is commonly used as an index of myocardial contractility; the shorter the PEP, the greater the myocardial contractility (Fergusson, Gledhill & Jamnik, 2001).

Numerous studies have reported that PEP levels off at submaximal work rates (Gledhill, Cox & Jamnik, 1994; Fergusson, Gledhill & Jamnik, 2001; Krip et al., 1997; Rivera et al., 1989; Van Fraechem, 1979; Warburton et al., 1999). The levelling off of PEP coincides with a plateau in total peripheral resistance (TPR) at a submaximal work rate. Thus, the drop in TPR and, therefore, LV afterload observed from pre-exercise to submaximal work rates reflect increases in contractility. However, TPR does not decrease beyond submaximal exercise work rates, whereas SV continues to increase, suggesting that adaptations in preload, not contractility, account for SV increases at higher work rates. These findings indicate that SV augmentation throughout heavy to maximal exercise, and the enhancement of SV at higher work rates, may rely increasingly on the Frank-Starling mechanism rather than myocardial contractility (Fergusson, Gledhill & Jamnik, 2001). According to the Frank-Starling effect, an increase in venous return to the LV at an unchanged afterload enhances preload. It results in a more significant stretch of the myocardial fibres, creating a more optimal interaction of actin and myosin filaments, increasing elastic potential energy for additional contractile force, which allows the heart to empty to the same extent in a shorter time despite the extra volume presented to the heart (Gledhill, Cox & Jamnik, 1994, Krip et al., 1997; Warburton et al., 1999; Allen & Kentish, 1985).

Although the SV is increasing, filling time accounts for a decreasing portion of the R-R interval. However, although the diastolic filling rate (DFR) and left ventricular emptying rate (LVER) are increasing, DFR is increasing much more. DFR is approximately 1.5 times greater than LVER during maximal exercise. This augmented DFR is attributed to an enhanced venous return, faster myocardial relaxation, a sucking effect the heart created by myocardial recoil, and more effective atrial contraction (Crawford, Petru & Rabinowitz, 1985; Fagard, Van den Broeke & Amery, 1989; Gledhill, Cox & Jamnik, 1994; Matsuda et al., 1983). Thus, the progressive increase in SV is attributed to enhancements in DFR and LVER, with the primary advantage being the DFR (Gledhill, Cox & Jamnik, 1994).

1.2.4. Peripheral factors that affect VO_2max

The cellular mechanisms contributing to O_2 extraction within skeletal muscle also increase at a predictable rate during incremental to maximal intensity exercise. However, increases in VO_2 during incremental to maximal intensity exercise are due primarily to linear increases in Q. Therefore, the peripheral mechanisms are viewed as a complement to the central mechanisms contributing to VO_2max (Beltz et al., 2016).

1.2.5. Endurance training and VO_2max

The mean improvements in VO_2max with endurance training have been about 25%, ranging from 0% to 40% (Bouchard et al., 1995; Bouchard & Rankinen, 2001). The physiological reason for the wide range of responses to physical training remains unclear. Maximal stroke volume (SVmax) and maximal cardiac output (Qmax) are higher in endurance-trained athletes, and increases in SVmax and Qmax are primarily responsible for the increase in VO_2max with regular vigorous-intensity endurance training (Saltin, 1969). The SV of endurance-trained athletes is considerably larger than the SV of untrained individuals (Astrand et al., 1964; Bevegard, Olmgren & Jonsson, 1963; Wang, Marshall & Shepherd, 1960; Krip et al., 1997), and SV has been shown to increase progressively throughout incremental work rates to maximum (Crawford, Petru & Rabinowitz, 1985; Ekblom et al., 1968; Gledhill, Cox & Jamnik, 1994; Krip et al., 1997; Rivera et al., 1989; Van Fraechem, 1979).

To augment SV, endurance-trained athletes rely on ventricular filling and emptying enhancements. However, the significant difference in exercise cardiac function between endurance-trained and untrained individuals is in the DFR due to greater ventricular preload and compliance (Gledhill, Cox & Jamnik, 1994). Despite the shorter dt, the ventricular filling is not restricted. The primary advantage in exercise cardiac function of endurance-trained individuals over untrained individuals is an enhanced diastolic (rather than systolic) function (Gledhill, Cox & Jamnik, 1994, Krip et al., 1997). The difference between the DFR of endurance-trained and untrained individuals is mainly attributable to the higher blood volume (BV) of endurance-trained individuals (Gledhill, Cox & Jamnik, 1994).

BV is one of the many physiological characteristics that adaptively increase in response to endurance training, so endurance-trained individuals have a larger BV than untrained individuals (Akgun et al., 1976; Convertino, 1991). Q and SV both increase when BV is augmented (Coyle, Hopper & Coggan, 1990; Hopper, Coggan & Coyle, 1988; Kanstrup & Ekblom, 1982; Krip et al., 1997), and there is a strong relationship between BV, diastolic function, and aerobic fitness (Levine, 1993). The mean BV of endurance-trained male subjects is 95-100 $mL \cdot kg^{-1}$, whereas the mean BV of normally active male subjects is typically 70-80 $mL \cdot kg^{-1}$ (Hopper, Coggan & Coyle, 1988; Kjellberg, Rudhe & Sjorstrand, 1949). Further, after endurance training, BV has been reported to increase from 75 $mL \cdot kg^{-1}$ to 90-100 $mL \cdot kg^{-1}$ (Dill & Costill, 1974; Kjellberg, Rudhe & Sjorstrand, 1949). A larger BV causes an increased central venous pressure and an elevated venous return. These increases augment ventricular preload, which enhances ventricular filling and results in a higher EDV (Hopper, Coggan & Coyle, 1988; Kanstrup & Ekblom, 1982). An augmented EDV increases and capitalizes on the Frank-Starling mechanism resulting in a larger SV being ejected. Additionally, aerobically trained individuals with a larger BV have a lower maximal TPR, which results in a lower myocardial afterload, which could lead to a decreased ESV and, thus, a larger SV (Hopper, Coggan & Coyle, 1988).

BV has such a direct effect on aerobic fitness and endurance performance that unscrupulous coaches, athletes, and practitioners have sought artificial means of increasing BV through blood doping and recombinant erythropoietin (Pavelka, 1985). These techniques, wherein whole or reconstituted blood is (re)infused into participants, have been reliably shown to enhance cardiac function, VO_2max and endurance performance (Brien & Simon, 1987; Buick et al., 1980; Celsing et al., 1987; Roberston et al., 1982; Spriet, Heigenhauser & Jones, 1986; Gledhill, 1982; Gledhill, 1985). The ergogenic effect of "blood doping" is due primarily to alterations in total hemoglobin (Hb) and red cell volume, leading to an enhancement in oxygen transport (Warburton et al., 1999). Systemic oxygen transport is calculated as arterial oxygen content multiplied by Q (Gledhill & Jamnik, 1992; Gledhill, Warburton, & Jamnik, 1999). Arterial O_2 content is largely determined by combining O_2 with Hb (Gledhill, Warburton, & Jamnik, 1999). The higher the [Hb], the greater the O_2-carrying capacity of the blood. At a constant Q, an increase in [Hb] will enhance O_2 transport to the working muscles, allowing for an increased VO_2max and aerobic performance (Gledhill, Warburton, & Jamnik, 1999). Blood doping techniques commonly increase [Hb] and bring about a concomitant rise in O_2-carrying capacity, allowing for improved VO_2max, endurance performance, or both (Gledhill, Warburton, & Jamnik, 1999). Investigations in which BV is increased by plasma volume expansion (PVexp) provide varying results. Some researchers have found that PVexp results in an unchanged VO_2max despite an increased SV and Q. This unchanged VO_2max is most likely due to the offsetting of hemodilution on O_2 transport (Green et al., 1987; Kanstrup & Ekblom, 1982). However, others have observed that if the increases in SV and Q are proportionately greater than the hemodilution effects of PVexp on O_2 content, then VO_2max could be increased (Convertino, 1983; Coyle, Hopper & Coggan, 1990). However, BV expansion in elite endurance athletes, who already possess a high BV, does not improve VO_2max or endurance performance (Warburton et al., 1999). This may be because elite endurance athletes are already at an optimal BV, at or near the limits of their diastolic reserve capacity (Warburton et al., 1999).

1.2.6. Resistance training and VO_2max

The traditional consensus indicates that heavy resistance training does not significantly affect VO_2max. This is attributed to the lack of continuity during resistance exercise (i.e., the relatively long rest periods between sets), which poses limitations for potential improvements in VO_2max (Kraemer, Ratamess & French, 2002). Although large muscle mass exercise workouts have been shown to elicit responses in VO_2, peaking at 60% of VO_2max (Tesch, 1992), this may not reach the critical threshold needed for aerobic fitness improvement. Circuit training and high-volume resistance programs with short rest periods (i.e., 30 seconds or less) have been shown to improve VO_2max (Gettman, Culter & Strathman, 1980). Therefore, increasing the aerobic component of resistance training by decreasing rest periods and keeping the volume high may be an effective way to improve VO_2max. However, the net gain is considerably less than when performing continuous or intermittent vigorous to maximal intensity aerobic exercise training.

1.2.7. The measurement of VO_2max

Various methods and protocols can be used to assess an individual's VO_2max. These include indirect estimations and the measurement of VO_2max using indirect calorimetry via open circuit spirometry. Predictive methods use various submaximal and maximal intensity ergometry and field tests (e.g., the Leger 20-meter shuttle run test, the YMCA cycle ergometer test, the Ebbeling single-stage walking test, etc.) to predict VO_2max (Heyward, 2010). However, the gold standard or criterion for measuring VO_2max during incremental to maximal intensity exercise is indirect calorimetry using open-circuit spirometry and gas analysis during a GXT (Beltz et al., 2016).

During indirect calorimetry, rapid response gas analyzers are used to measure fractional concentrations of O_2 and CO_2, and ventilation measurement devices (e.g., Tissot gasometers, Douglas bags, pneumotachometers, flow meters, etc.) are used to collect inspired and expired air volumes. These test variables are then used to calculate VO_2 using the Haldane transformation equation:

$$VO_2 = (V_I \times F_IO_2) - (V_E \times F_EO_2)$$

Where F_IO_2 is the fraction of O_2 in inspired air, F_EO_2 is the fraction of O_2 in expired air, V_I is the volume of inspired air, and V_E is the volume of expired air.

1.2.8. Chronic diseases and pathological conditions

Due to the widespread applications and relevance of VO_2max, normative criteria have been established to help practitioners categorize cardiovascular disease states and prognoses (Albouaini et al., 2007). VO_2max also has substantial clinical utility for measuring and understanding aging dysfunction and various pathological conditions impacting pulmonary, cardiovascular, and muscle systems, from chronic heart failure and diabetes to HIV-AIDS. The power of VO_2max to noninvasively determine the efficacy of exercise training programs and other ergogenic strategies in health, and therapeutic interventions in disease conditions, is tremendous (Poole & Jones, 1985). The assessment of VO_2max has been used to establish the relationship between cardiorespiratory fitness (CRF), cardiovascular disease (CVD), and all-cause mortality (Blair, Kampert & Kohl, 1996). Additionally, researchers have underscored low aerobic fitness as a predictor of all-cause mortality and future CVD (Blair, Kampert & Kohl, 1996; Blair, Kohl &

Barlow, 1995). Further, a meta-analysis by Kodama, Saito & Tanaka (2009) showed that a 1-MET (3.5 $mL \cdot kg^{-1} \cdot min^{-1}$) increase in VO_2max was associated with a 13% reduction in risk of all-cause mortality and a 15% reduction in CVD. The threshold to classify a significantly higher risk for all-cause mortality and CVD was established as a VO_2max < 7.9 METS (27.7 $mL \cdot kg^{-1} \cdot min^{-1}$).

1.2.9. Endurance and non-endurance sports

All endurance athletes possess high aerobic fitness levels, and it is widely accepted that it plays an important role in athletes' success. As such, VO_2max is often used by exercise physiologists and strength and conditioning coaches to assess whether their athletes are competition ready. In endurance events such as marathons, triathlons and distance cycling events, where performance success is directly related to aerobic fitness, it is common for elite-level athletes to have extremely high VO_2max values. For example, Table 1 lists several world-class endurance athletes and their corresponding VO_2max values. These VO_2max values range from 69.7 to 90.0 $mL \cdot kg^{-1} \cdot min^{-1}$ and are significantly greater than the VO_2max values found under the "superior" classification in the normative VO_2max table (Table 2).

Table 1. Aerobic fitness of elite-level athletes in various endurance sports.

Athlete	Sex	Age, yr	Sport	VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$
Bjorn Daehle	m		Cross-country skier	90.0
Miguel Indurian	m		Cyclist (winner of Tour de France)	88.0
John Ngugi	m		5x world cross-country champion	85.0
Dave Bedford	m		10 km running world record holder	85.0
Steve Prefontaine	m		1 mile in 3:56.60	84.4
Lance Armstrong	m		Cyclist (winner of Tour de France)	84.0
Joan Benoit	f		Marathon runner (2:24:52)	78.6
Bill Rogers	m		Marathon runner (2:09:27)	78.5
Sebastian Coe	m		Middle distance runner (1 mile WR)	77.0
Grete Waltz	f		Marathon runner (WR 1980)	73.0
Frank Shorter	m		Marathon runner	71.0
Derek Clayton	m		Marathon runner (WR 1969)	69.7
Peter Fonsecca*	m		Marathon runner	84.0
Ed Whitlock*	m	80	Marathon runner	50.0
Nicholas Latifi*	m	21	Formula 2 race car driver	58.7
Lisa Bentley*	f		Triathlete	63.0

*Data was collected in the Human Performance Laboratory at York University.

Table 2. Aerobic fitness classifications in the general public.

	Age, yr	Poor	Fair	Good	Excellent	Superior
Male	20-29	$\leq$ 41	42-45	46-50	51-55	56+
	30-39	$\leq$ 40	41-43	44-47	48-53	54+
	40-49	$\leq$ 37	38-41	42-45	46-52	53+
	50-59	$\leq$ 34	35-37	38-42	43-49	50+
	60-69	$\leq$ 30	31-34	35-38	39-45	46+
	70-79	$\leq$ 27	28-30	31-35	36-41	42+
Female	20-29	$\leq$ 35	36-39	40-43	44-49	50+
	30-39	$\leq$ 33	34-36	37-40	41-45	46+
	40-49	$\leq$ 31	32-34	35-38	39-44	45+
	50-59	$\leq$ 28	29-30	31-34	35-39	40+
	60-69	$\leq$ 25	26-28	29-31	32-36	37+
	70-79	$\leq$ 23	24-26	27-29	30-36	37+

Note: VO_2max is measured in $mL \cdot kg^{-1} \cdot min^{-1}$.
Adapted from Gibson, Wagner & Heyward (2018).

The average VO_2max of a 70 kg man is approximately 3 $L \cdot min^{-1}$ or 43 $mL \cdot kg^{-1} \cdot min^{-1}$, but it is greatly influenced by genetic factors, fitness and type of training, age, gender and body composition (Shvartz & Reibold, 1990). On the other hand, there remains much debate as to whether VO_2max correlates to better performance than other variables in elite non-endurance sports such as ice hockey, football and soccer.

It is apparent in Table 3 that elite non-endurance athletes also have relatively high VO_2max values compared to non-endurance athletes. The VO_2max values in Table 3 range from 35 – 75 $mL \cdot kg^{-1} \cdot min^{-1}$ in women and 38 – 85.2 $mL \cdot kg^{-1} \cdot min^{-1}$ in men and fall within the good, excellent and superior categories of the normative VO_2max table (Table 2). Tables 1 and 3 demonstrate that endurance and non-endurance athletes possess high aerobic fitness levels relative to the general population.

Table 3. VO_2max of elite athletes in various non-endurance sports.

Sport	Age, yr	Male	Female
Baseball	18-32	48-56	
Basketball	18-30	40-60	43-60
Football	20-36	42-60	
Gymnastics	18-22	52-58	36-50
Ice hockey	10-30	50-63	
Racquetball	20-35	55-62	50-60
Rowing	20-35	55-62	50-60
Skiing, alpine	18-30	57-68	50-55
Soccer	22-28	54-64	50-60
Speed skating	18-24	56-73	44-55
Swimming	10-25	50-70	40-60
Track & Field, discus	22-30	42-55	
Track & Field, 400-m running event	19-23	52-70	
Track & Field, 800-m running event	21-28	65-74	
Volleyball	18-22		40-56
Weightlifting	20-30	38-52	
Wrestling	20-30	52-65	

Note: VO_2max is measured in $mL \cdot kg^{-1} \cdot min^{-1}$.
Adapted from Wilmore & Costil (2005).

VO_2max outcomes are also routinely used to evaluate the effectiveness of exercise training interventions, monitor elite athlete development and measure functional capacity in a wide range of occupations (Day et al., 2003; Elsner & Kolkhorst, 2008; Gledhill, Jamnik & Shaw, 2001; Gledhill & Jamnik, 1992; Gledhill, 1995; Marchant et al., 1995; Davis & Dotson, 1987; Lemon & Herminston; 1977; Misner, Plowman & Boileau, 1987). As well as providing baseline information VO_2max reflects changes in aerobic fitness over time.

1.2.10. Physically demanding public safety occupations

Job-related physical employment standards are used to determine whether or not applicants and return-to-work incumbents possess the physical and physiological characteristics required to safely and efficiently perform the critical physically demanding on-the-job tasks encountered during emergency situations. Typically, physical employment standards can only be implemented in public safety occupations in which ineffective job performance can result in loss of life and/or property (e.g., structural firefighters, wildland firefighters, police officers, correctional officers, etc.). In Canada, it is common for physically demanding public safety occupations to establish physical employment standards that conform to specific legal requirements, including: government law, human rights legislation, court decisions, case law, expert consensus on the subject matter and 'best practises' to qualify as bona fide occupational requirement (BFOR)(Jamnik, Gumienak & Gledhill, 2013). The physical employment standards that qualify as BFOR in physically demanding public safety occupations demonstrate the employer's due diligence in addressing potential threats to public safety and property (Gledhill & Jamnik, 1992; Jamnik et al., 2010; Gumienak, Jamnik & Gledhill, 2013). Although a physical employment standard is developed with the purpose of meeting the requirements to qualify as a

BFOR, the designation that the physical employment standard is a BFOR only happens when a human rights tribunal or court rules that the specific physical employment standard qualifies as a BFOR (Jamnik, Gumienak & Gledhill, 2013). This generally only occurs when an unsuccessful candidate pursues an official legal challenge against a physical employment standard.

In Canada, the 1999 Supreme Court of Canada's Meiorin Decision requires employers to answer "Unified Test" questions to demonstrate that a physical employment standard is justifiably discriminatory and thereby qualifies as a BFOR (SCCMD, 1999) (Table 4).

Table 4. The "Unified Test" questions established by the 1999 Supreme Court of Canada's Meiorin Decision.

1. Is the standard, policy or practice discriminatory and based on a prohibited ground?
2. Was the adoption of the standard, policy or practice rationally connected to the performance of the job?
3. Did the employer adopt the particular standard, policy or practice in an honest and good faith belief that it was necessary to fulfill that legitimate work-related purpose?
4. Is the standard, policy or practice least discriminatory and reasonably necessary to fulfill that legitimate work-related purpose such that it would be impossible to accommodate individual employees without imposing undue hardship on the employer?

Supreme Court of Canada Meiorin Decision, 1999.

As such, to qualify as a BFOR a physical employment standard must be based on both "safe" (properly executing the critical life threatening physically demanding emergency tasks) and "efficient" (completing these tasks in a time frame that is suited to the emergency circumstance) job performance (Jamnik, Gumienak & Gledhill, 2013). What is determined as "safe and efficient" job performance is determined by occupation-specific subject matter experts. Furthermore, the critical physically demanding and frequently occurring job-related tasks must 1) not be based on the physical fitness characteristics of current front-line workers and 2) be based on the "safe and efficient" work performance of the current front-line work force (taking into account the divers individualities of the workers with respect to age, sex, minority status, disability status, and work experience (Tipton, Milligan & Reilly, 2012). Finally, the physical employment standard must be based on the current ability to perform the job tasks and not on the future likelihood of failure to perform the job. In general, this means that the requirements built into physical employment standards are based on the performance of "safe and efficient" front-line female rather than male workers, although the sub-group could also be age defined. The pivotal outcome of the SCCMD (1999) was the establishment of a "best practices" systematic research process template for developing physical employment standards that qualify as a BFOR (Gledhill & Bonneau, 2001).

Physical employment standards are composed of simulated job tasks, fitness components that underlie job performance, or a hybrid of these two approaches (Bonneau, 2001). A hybrid physical employment standard includes both simulated job tasks and one (or more) fitness component test(s); most often, this fitness component is an aerobic fitness (VO_2max) test (Gledhill, 1995; Gledhill, Jamnik & Shaw, 2001; Jamnik & Gledhill, 1992). Hybrid physical employment standards with a separate aerobic fitness assessment are typically used for applicant screening, whereas job simulation circuits with an embedded aerobic fitness requirement are more commonly used for the annual assessment of incumbent workers. Therefore, it is important for applicants to physically demanding public safety occupations to have their aerobic fitness directly measured as part of their pre-employment physical fitness screening protocols to ensure that they possess the VO_2max required to perform their job safely and efficiently (Gledhill & Jamnik 1992; Jamnik et al., 2010; Gumienak, Jamnik & Gledhill, 2013) (Table 5). Research advocates that structural firefighters develop and maintain an aerobic fitness, as measured by maximal oxygen consumption (VO_2max), of at least 42.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (Storer et al., 2014). This job-related aerobic fitness standard for structural firefighters allows for a 10-15% reserve capacity, above 41.5 $mL\cdot kg^{-1}\cdot min^{-1}$ that offers structural firefighters a margin of safety when performing the most physically demanding critical job tasks (Gledhill & Jamnik, 1992) and ensures that they are physically capable of performing any emergency job task in a safe and efficient manner (Smith, 2011).

Table 5. The VO_2max of front-line incumbents while performing the critical physically demanding on-the-job tasks.

Public Safety Occupations	VO_2max ($mL\cdot kg^{-1}\cdot min^{-1}$)
Structural firefighters	41.5 ± 4.2
Nuclear power	36.0 ± 4.6
Wildland firefighters	46.8 ± 5.0
Ontario police	40.5 ± 4.0
Alberta police	41.6 ± 2.6
Correctional officers	36.6 ± 4.4

Note: VO_2max is measured in $mL\cdot kg^{-1}\cdot min^{-1}$.
Values are presented as mean ± standard deviation.
Adapted from Jamnik, Gumienak & Gledhill (2013).

Despite similar legal systems among common law countries (e.g., Canada, the United States, the United Kingdom and Australia), most jurisdictions have developed their own laws concerning the legality and implementation of physical employment standards in isolation from one another (Adams, 2016). This being said, Canada, the United States, the United Kingdom and Australia each employ a reasonably similar model of dealing with workplace discrimination, and physical employment standards. What make Canada unique, is that it is the only jurisdiction where the highest court had directly dealt with a case involving physical employment standards (SCCMD, 1999). Therefore, the Canadian laws on physical employment standards are arguably the best developed and most consistent.

1.2.11. Military and armed forces

The Canadian Armed Forces (CAF) must also conform to the Canadian Human Rights Act and meet BFOR when implementing a physical fitness standard. The Fitness for Operational Requirements of Canadian Armed Forces Employment (FORCE) evaluation qualifies as a BFOR since it is not a physical fitness evaluation, but rather “a reflection of the Canadian Armed Forces’ minimal physical employment standard related to common defence and security duties known as the Universality of Service” (Canada, 2015). The FORCE test is as a measurement of a person’s suitability for military duty and not as an assessment of that person’s fitness level. Its’ standards are based on, and have been scientifically validated against, the performance of general, environmental, occupational, and operational duties. (Canada, 2013). The FORCE evaluation is administered annually to all CAF personnel except those subject to task-specific or special operations unit evaluations (e.g., Join Task Force 2, Canadian Special Operations Regiment, officer cadets at the Royal Military College of Canada, military firefighters, search and rescue personnel and military divers).

CHAPTER 2: MANUSCRIPT I

Performing a verification phase immediately after an incremental to maximal graded exercise test increases the proportion of participants who meet the job-related aerobic fitness standard for structural firefighters.

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2.1. OVERVIEW

Incremental to maximal graded exercise tests (GXT) performed to volitional fatigue are routinely used to measure the aerobic fitness/maximal oxygen consumption (VO_2max) of firefighter applicants and ensure that they meet the job-related aerobic fitness standard. During the incremental to maximal GXT, primary and secondary criteria are used to confirm the attainment of a VO_2max. However, these criteria are sometimes inconsistent and present with great inter-subject variability, which compromises their sensitivity and reliability. This can result in erroneously accepting a VO_2peak as a VO_2max. Therefore, a viable alternative needs to be identified to confirm the measurement of an accurate VO_2max (Thoden, MacDougall & Wilson, 1991). A verification phase (VP) used immediately after the incremental to maximal GXT has been proposed as a the new "gold standard" protocol. The research aims of this study were to 1) determine how many participants were able to attain their VO_2max during the GXT and how many participants required the VP, 2) for those participants who required the VP to reach their VO_2max, compare their VO_2peak values measured during the GXT to their VO_2max values measured during the VP, and 3) determine if the use of a VP significantly increased the proportion of participants who meet the aerobic fitness standard for structural firefighters.

4462 study participants (4179 males and 283 females) completed an incremental to maximal GXT and, if required, a VP to measure their VO_2max. For the participants who required a VP to attain their VO_2max, their VO_2peak values measured during the GXT were compared to their VO_2max values measured during the VP using paired-samples t-tests. The proportion of participants who met the job-related aerobic fitness standard during the GXT was compared to that of those who met the job-related aerobic fitness standard during the VP using a McNemar test with continuity correction. Only 24.6% of participants were able to attain their VO_2max during the GXT. This means that 75.4% of participants were only able to attain a VO_2peak during the GXT and required the VP to attain their VO_2max. For these participants, the VO_2peak values measured during the GXT were significantly lower than the VO_2max values measured during the VP ($p < 0.001$). Because of this, the proportion of participants who met the job-related aerobic fitness standard for structural firefighters increased from 79.8% during the GXT to 92.6% during the VP, a statistically significant increase ($p < 0.001$). These findings support the use of a VP, immediately following a GXT, to confirm the attainment of an accurate and valid VO_2max.

2.2. INTRODUCTION

Firefighting is a physically demanding public safety occupation, that under emergency circumstances, may require front-line firefighters to work at vigorous intensity for sustained periods of time (Gledhill & Jamnik, 1992). It requires heavy lifting and maneuvering while wearing personal protective equipment (PPE) in high ambient temperatures under stressful conditions (Barr, Gregson & Reilly, 2010). These physical and psychological stressors contribute to the rates of injury and adverse cardiovascular events among firefighters (Smith, Barr & Kales, 2013; Kales et al., 2007; Soteriades et al., 2011). In fact, the highest cause of on-duty firefighter fatalities is sudden cardiac death attributed to low levels of aerobic and physical fitness (Fahy, LeBlanc & Molis, 2012). For these reasons, successful job performance and individual safety depend largely on the physical fitness levels of firefighters (Gledhill & Jamnik, 1992). Research advocates that firefighters develop and maintain an aerobic fitness, as measured by maximal oxygen consumption (VO_2max), of at least 42.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (Storer et al., 2014). This job-related aerobic fitness standard for structural firefighters allows for a 10-15% reserve capacity that offers firefighters a margin of safety when performing the most physically demanding critical job tasks (Gledhill & Jamnik, 1992) and ensures that they are physically capable of performing any emergency job task safely and efficiently (Smith, 2011).

Therefore, structural firefighter applicants and returning-to-work incumbents routinely have their VO_2max estimated or directly measured using submaximal or maximal aerobic fitness tests, respectively. Submaximal tests are less expensive and easier to administer, making them more practical to implement (Dolezal et al., 2015). However, there are limitations in the accuracy of VO_2max estimations based on submaximal tests. Submaximal tests assume a linear relationship exists between heart rate and oxygen consumption during incremental exercise and rely on maximal heart rate prediction equations to predict VO_2max (Astrand & Ryhming, 1954; Margaria, Aghemo & Rovelli, 1965). For this reason, VO_2max estimations based on submaximal tests become increasingly inaccurate for those significantly above or below the average aerobic fitness level (Mier & Gibson, 2004). In other words, submaximal tests often overestimate the aerobic fitness of less fit individuals and underestimate the aerobic fitness of more fit ones (Mier & Gibson, 2004). For more fit individuals, this increases the likelihood that false conclusions may be made about their aerobic fitness and could negatively impact their ability to meet the job-related aerobic fitness standards for structural firefighters. Overestimating the VO_2max of those individuals with lower aerobic fitness levels may lead to falsely meeting the aerobic fitness standard, placing firefighters at risk of less effective work performance, injury or cardiovascular events on duty (Dolezal et al., 2015).

On the contrary, VO_2max is most accurately measured during incremental to maximal graded exercise tests (GXT) using indirect calorimetry and open circuit spirometry. A variety of standardized incremental to maximal GXT protocols exist (e.g. Bruce, Balke-Ware, Astrand, etc.); however, these protocols are generally based on an intended for use on specific populations. These standardized GXT protocols use systematic increases in exercise intensity (e.g., progressive ramp or step increments) over time until the individual cannot tolerate the workload (i.e., volitional fatigue) or reaches their VO_2max. During the incremental to maximal GXT, select cardiovascular, pulmonary and metabolic variables are collected to evaluate exercise tolerance and represent the efficiency with which the pulmonary, cardiovascular and metabolic systems can uptake, deliver and utilize oxygen. However, protocol characteristics such as initial exercise intensity, workload increments, stage duration, and total test duration may individually or in combination limit the accuracy of incremental to maximal GXT. For this reason, there is an ongoing debate regarding the appropriateness of current standardized GXT guidelines, thereby limiting the ability to compare results between tests and populations. Furthermore, the criteria used to confirm attainment of VO_2max are not always consistent or universally applied.

To increase the reliability and validity of aerobic fitness tests, primary and/or secondary criteria are applied to substantiate the attainment of a VO_2max. The achievement of a VO_2 plateau (e.g., changes $\leq$ 150 $mL \cdot min^{-1}$ or 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ between two consecutive stages despite an increase in exercise intensity) is the primary criterion used to confirm attainment of a "true" VO_2max (Bassett & Howley, 2000; Taylor, Buskirk & Henschel, 1955). However, since VO_2 plateaus are not always attained in all tested individuals when performing an incremental to maximal GXT, several secondary criteria are applied; a respiratory exchange ratio (RER) of 1.00 – 1.15, a blood lactate concentration of $\geq$ 8 $mMol \cdot L^{-1}$ and a heart rate (HR) > 90% of age-predicted HRmax (Howley, Bassett & Welch, 1995). However, using these secondary criteria to validate the attainment of a VO_2max has been criticized due to the high degree of inter-subject variability in attaining these criteria (Poole & Jones, 1985). Furthermore, the number of criteria used to determine VO_2max is often contingent on the preference of the researcher or clinician administering the GXT.

Consequently, a verification phase (VP) has been proposed as an alternative solution (Thoden, MacDougall & Wilson, 1991). The VP uses one or more bouts of supramaximal intensity exercise (e.g. an intensity higher than that achieved during the last workload of the incremental test) after the incremental to maximal GXT until a VO_2max is attained, as confirmed by the presence of a VO_2 plateau (Beltz et al., 2016). The VP is particularly important for non-athletic populations who may not possess the work tolerance required to exercise continuously for a sufficient duration and intensity to fully tax their aerobic system and reach their VO_2max during the commonly used incremental to maximal GXT alone. Some individuals may require a VP following the incremental to maximal GXT to accurately measure their VO_2max and not just their VO_2peak.

It is important to point out that a difference exists between VO_2peak and VO_2max, even though these terms are often used interchangeably in the literature (Beltz et al., 2016; Chia, Aziz & Teh, 2007). VO_2peak is the highest value attained during continuous exercise to volitional fatigue and represents an individual's exercise tolerance whereas VO_2max represents the highest physiological attainable value (Day et al., 1985). A VO_2max is always a VO_2peak but a VO_2peak is not always a VO_2max. In fact, the difference between VO_2peak and VO_2max is most commonly determined by the presence of the VO_2 plateau.

This study aimed to determine if there were significant differences between the VO_2peak values measured during the incremental to maximal GXT and the VO_2max values measured during the VP. Secondly, we wanted to determine if using a VP immediately after an incremental to maximal GXT would significantly increase the proportion of participants who meet the aerobic fitness standard for structural firefighters. Finally, we wanted to determine if there were any differences in descriptive characteristics (e.g. sex, age, height, body mass, and body mass index (BMI)) between those participants who attained their VO_2max during the GXT and those participants who required the VP to attain their VO_2max.

It was hypothesized that a number of study participants would not attain their VO_2max during the incremental to maximal GXT but would after completing the VP. In other words, we hypothesized that a number of VO_2 values measured during the incremental to maximal GXT would be VO_2peak values and not VO_2max values. If this were the case, the percentage of study participants who meet the job-related aerobic fitness standard for structural firefighters after the incremental to maximal GXT would be significantly less than that if the values measured during the VP were used. Finally, it was hypothesized that individuals who required the VP to reach their VO_2max would be older and have greater body mass and BMI values.

2.3. METHODS

2.3.1. Study participants

4462 (4179 male and 283 female) structural firefighter applicants and returning-to-work incumbents completed an aerobic fitness test as part of a more comprehensive physical fitness assessment (e.g., Structural Firefighter Fitness Assessment (SFFA)). Each participant provided written informed consent and agreed to have their data analyzed and reported in an anonymized group format in future analysis. This study was approved by the York University Human Participants Review Committee, whose research ethics guidelines are in accordance with the Canadian Tri-Council research ethics (**Certificate #: E2019-235**). Prior to the aerobic fitness test, each participant completed the Physical Activity Readiness Questionnaire For Everyone (PAR-Q+) and, if necessary, the ePARmed-X+ (www.eparmedx.com) to ensure that they were cleared for unrestricted physical activity (e.g. moderate to maximal intensity exercise). In addition, pre-exercise blood pressure and pulse rate measurements were taken by qualified exercise professionals using the automated BpTRU (BpTRU Medical Devices Ltd., Coquitlam, BC, Canada) blood pressure device. These pre-exercise measurements were solely used to clear participants for unrestricted physical activity and were not included in the data analysis.

Following the pre-exercise screening procedure, all participants had selected demographic (e.g., sex and age) and anthropometric data (e.g., height, body mass and body mass index (BMI)) collected. Height was measured without footwear using a wall-mounted stadiometer (Seca MPH07SH3 Mechanical Wall Mount Stadiometer, Germany) to the nearest 0.01 m, and body mass was measured while wearing light clothing and no footwear using a digital floor scale (Seca 876 Digital Floor Scale, Germany) to the nearest 0.1 kg. Body mass index (BMI) was calculated as body mass (kg) divided by height squared (m^2).

2.3.2. Aerobic fitness test

Each participant completed an aerobic fitness test (a modified Astrand protocol) on a motorized treadmill (Woodway Pro XL, Waukesha, WI, USA) using step increases in work intensity (Table 6).

Table 6. Example aerobic fitness test protocol.

Phase	Stage	Time (min)	Speed (mph)	Grade (%)
Warm-Up	Warm-Up	1	3.5	2.0
		2		
		3		
		4		
		5		
Graded Exercise Test	Workload #1	6	5.0	2.0
		7		
	Workload #2	8	6.0	2.0
		9		
	Workload #3	10	7.0	2.0
		11		
	Workload #4	12	7.0	4.0
		13		
	Workload #5	14	7.0	6.0
		15		
	Workload #6	16	7.0	8.0
		17		
	Workload #7	18	7.0	10.0
		19		
Verification Phase (could be more than 2 if necessary)	Active Recovery	20	3.5	2.0
		21		
	Verification Workload #1	22	7.0	12.0
		23		
	Active Recovery	24	3.5	2.0
		25		
	Verification Workload #2	26	7.0	14.0
		27		
Cool-Down	Cool-Down	28	3.5	2.0
		29		
		30		

Note: This example applies to all individuals who have a body mass < 75 kg. Individuals with a body mass ≥ 75 kg, start at an incline of 4.0% instead of 2.0% and follow the same progression.

Prior to the commencement of the aerobic fitness test, study participants performed a brief 5-minute walking warm-up on the treadmill at 3.5 mph and 2.0% incline during which they were given the test instructions and familiarized with the test equipment. Participants began the incremental to maximal GXT by running at 5.0 mph at an incline of 2.0% or 4.0% depending on their body mass (e.g. if their body mass was < 75.0 kg an incline of 2.0% was used and if their body mass was ≥ 75.0 kg, an incline of 4.0% was used) for 2 minutes. During each subsequent 2-minute workload, the incline was kept constant and the speed of the treadmill was increased by 1.0 mph until a suitable running speed was achieved (e.g. between 6.0 and 7.0 mph) depending on individual running biomechanics and gait. Once the desired running speed was achieved, the speed of the treadmill was kept constant and the incline of the treadmill was progressively increased by 2.0% during each subsequent 2-minute workload until participants either attained an accurate VO_2max, or were no longer physically able to continue (i.e., volitional fatigue). The criterion that was used to determine the attainment of an accurate VO_2max was a VO_2 increase of less than 150 $ml \cdot min^{-1}$ or 2.1 $mL \cdot kg^{-1} \cdot min^{-1}$ despite an increase in exercise intensity between any two consecutive workloads (, during both the incremental GXT and VP) (i.e., a VO_2 plateau). Participants were instructed to give maximal effort and were verbally encouraged to run until volitional exhaustion was achieved. At that time, the treadmill speed and incline were reduced to 3.5 mph and 2.0%, respectively for a 2-minute active recovery period.

Participants who did not attain a VO_2max during the incremental to maximal GXT were given a 2-minute active-recovery period (i.e., 3.5 mph and 2.0% incline) before commencing the VP. The VP consisted of one or more 2-minute verification workloads separated by 2-minute active-recovery periods (i.e., 3.5 mph and 2.0% incline). During the VP, the speed of the treadmill was kept constant at the same speed as during the last workload of the incremental to maximal

GXT, and the incline was increased by 2.0% during each subsequent VW. One or more VW(s) were performed until a VO_2max was attained. Following the attainment of a VO_2max, the participants were given a 3-5 minute cool-down period during which they were instructed to walk on the treadmill at a speed of 3.0 mph and a grade of 0.0%.

Oxygen consumption (VO_2) was measured via indirect calorimetry using discrete component open circuit spirometry. Participants inhaled air from the atmosphere and exhaled air through a rubber mouthpiece, a two-way y-valve (Ewald Koegal Co., San Antonio, MA, USA) and a 1.5-inch flexible corrugated hose while wearing a plastic reusable nose clip (Harvard Apparatus model 59-9673, Holliston, MA, USA). Exhaled air was collected during the final 30-seconds of each 2-minute workload and analyzed by rapid response gas analyzers (Applied Electrochemistry, Model S-3A and CD-3S, Sunnyvale, CA, USA) for the fractional concentrations of oxygen (O_2) and carbon dioxide (CO_2). The O_2 and CO_2 analyzers were calibrated before and during each aerobic fitness test using gravimetrically analyzed gases.

2.3.3. Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics for Macintosh, version 27.0 (IBM Corp., Armonk, NY, USA). Independent-samples t-tests and chi-square tests of homogeneity were used to determine differences in physical characteristics between male and female participants. Differences in physical characteristics between those participants who attained their VO_2max during the incremental to maximal GXT and those that required a VP were examined using independent-sample t-tests and chi-square tests for homogeneity. For those participants that required a VP to attain their VO_2max, paired-sample t-tests were used to determine if there were significant differences between their VO_2peak values measured during the incremental to maximal

GXT and their VO_2max values measured during the VP. Finally, McNemar tests with continuity correction were used to determine whether the proportion of participants who met the aerobic fitness standard for structural firefighters was different when using the VO_2peak values measured during the incremental to maximal GXT compared to the VO_2max values measured during the VP. Differences in sex, age group and BMI group were also examined. The significance threshold was set at $P < 0.05$. Values are expressed as mean $\pm$ standard deviation (SD), unless otherwise stated.

2.4. RESULTS

2.4.1. Descriptive characteristics

4462 participants (4179 males and 283 females) completed an aerobic fitness test to measure their VO_2max and determine if they meet the aerobic fitness standard required of structural firefighters (> 42.5 $mL \cdot kg^{-1} \cdot min^{-1}$). Mean participant age, height, body mass, and body mass index (BMI) were 27.4 $\pm$ 6.0 years, 1.79 $\pm$ 0.07 m, 84.0 $\pm$ 12.3 kg and 26.3 $\pm$ 3.2 kg/m^2, respectively (Table 7). Male participants (1.79 $\pm$ 0.07 m) were significantly taller than female participants (1.68 $\pm$ 0.06 m), a statistically significant difference of 0.11 m (95% CI, 0.10 to 0.12), $t(4460) = 27.202$, $p < 0.001$. Male participants (85.0 $\pm$ 11.8 kg) had a significantly greater body mass than female participants (68.6 $\pm$ 8.7 kg), a statistically significant difference of 16.4 kg (95% CI, 14.99 to 17.79), $t(356.273) = 29.990$, $p < 0.001$. Male participants (26.4 $\pm$ 3.2 kg/m^2) had a significantly greater body mass index than female participants (24.2 $\pm$ 2.8 kg/m^2), a statistically significant difference of 2.2 kg/m^2 (95% CI, 1.81 to 2.57), $t(333.702) = 12.722$, $p < 0.001$. Male participants (51.6 $\pm$ 6.7 $mL \cdot kg^{-1} \cdot min^{-1}$) had a significantly greater VO_2max than female participants (45.5 $\pm$ 6.1 $mL \cdot kg^{-1} \cdot min^{-1}$), a statistically significant difference of 6.03 $mL \cdot kg^{-1} \cdot min^{-}$

1 (95% CI, 5.23 to 6.83), $t(4460) = -14.777$, $p < 0.001$. Finally, there were significantly more overweight or obese male participants (64.8%) than female participants

(32.5%), $p < 0.001$.

Table 7. Descriptive characteristics of study I participants stratified by sex.

Variable	Combined	Male	Female	P value
Sample size, n (%)	4462 (100.0)	4179 (93.7)	283 (6.3)	
Age, yr.	27.4 ± 6.0	27.5 ± 6.0	27.4 ± 5.7	0.976
Age group, n (%)				
Younger (< 30 yr.)	3098 (69.4)	2903 (69.5)	195 (68.9)	0.843
Older (≥ 30 yr.)	1364 (30.6)	1276 (30.5)	88 (31.1)	-
Height, m	1.79 ± 0.07	1.79 ± 0.07	1.68 ± 0.06	**<0.001****
Body mass, kg	84.0 ± 12.3	85.0 ± 11.8	68.6 ± 8.7	**<0.001****
BMI, kg/m^2	26.3 ± 3.2	26.4 ± 3.2	24.2 ± 2.8	**<0.001****
BMI group, n (%)				
Normal weight (< 25 kg/m^2)	1664 (37.3)	1473 (35.2)	191 (67.5)	**<0.001****
Overweight or obese (≥ 25 kg/m^2)	2798 (62.7)	2706 (64.8)	92 (32.5)	-
VO_2max, ml·kg^{-1}·min^{-1}	51.2 ± 6.8	51.6 ± 6.7	45.5 ± 6.1	**<0.001****

Values are presented as mean ± standard deviation unless otherwise stated.
BMI = Body mass index
Note: Independent-samples t-tests were used to determine significant differences between sexes except for proportions where chi-square tests for homogeneity were used.
**p < 0.001.

Descriptive characteristics from the incremental to maximal GXT and VP are reported in Table 8. A total of 1,096 (24.6%) participants attained their VO_2max during the incremental to maximal GXT and did not require a VP. However, 3,366 (75.4%) participants were not able to attain their VO_2max during the incremental to maximal GXT and required one or more verification workloads of the VP. Male participants who attained their VO_2max during the incremental to maximal GXT had greater body mass values (85.7 ± 12.4 kg) than those who required one or more verification workloads in order to attain their VO_2max (84.8 ± 11.5 kg), a statistically significant difference of 0.89 kg (95% CI, 0.03 to 1.75), $t(1634.275) = -6.420$, $p < 0.05$.

Table 8. Descriptive characteristics of study I participants stratified by the number of verification workloads required to attain their VO_2max.

Variable	0 VWs n=1096 (24.6)	≥ 1 VWs n = 3366 (75.4)	P value*
Sex, n (%)			
Male	1024 (93.4)	3155 (93.7)	0.723
Female	72 (6.6)	211 (6.3)	-
Age, yr.			
Male	27.6 ± 6.0	27.4 ± 6.0	0.435
Female	28.4 ± 6.0	27.1 ± 5.6	0.098
Combined	27.6 ± 6.0	27.4 ± 5.9	0.247
Age groups, n (%)			
Younger (< 30 yr.)	734 (67.0)	2364 (70.2)	**0.042***
Older (≥ 30 yr.)	362 (33.0)	1002 (29.8)	-
Height, m			
Male	1.80 ± 0.07	1.79 ± 0.07	0.376
Female	1.69 ± 0.07	1.68 ± 0.06	0.273
Combined	1.79 ± 0.07	1.79 ± 0.07	0.360
Body mass, kg			
Male	85.7 ± 12.4	84.8 ± 11.5	**0.043***
Female	69.2 ± 8.7	68.4 ± 8.7	0.490
Combined	84.6 ± 12.9	83.8 ± 12.0	0.059
BMI, kg/m^2			
Male	26.5 ± 3.2	26.3 ± 3.1	0.092
Female	24.2 ± 3.2	24.2 ± 2.6	0.866
Combined	26.4 ± 3.3	26.2 ± 3.2	0.110
BMI group, n (%)			
Normal weight (< 25.0 kg/m^2)	398 (36.0)	1266 (37.6)	0.440
Overweight or obese (≥ 25.0 kg/m^2)	698 (64.0)	2100 (62.4)	-

Values are presented as mean ± standard deviation unless otherwise stated.
VWs = Verification workloads, BMI = Body mass index
Note: Independent-samples t-tests were used to determine significant differences between groups except for proportions where chi-square tests for homogeneity were used.
*$p < 0.05$.

2.4.2. Verification phase test results

For those 3,366 study participants who required a VP to attain their VO_2max, their VO_2max values measured during the VP (51.7 ± 6.8 mL·kg^{-1}·min^{-1}) were greater than their VO_2peak values measured during the incremental to maximal GXT (47.0 ± 6.1 mL·kg^{-1}·min^{-1}), a statistically significant difference of 4.7 mL·kg^{-1}·min^{-1} (95% CI, (95% CI, 4.6 to 4.9), t(3365) = -

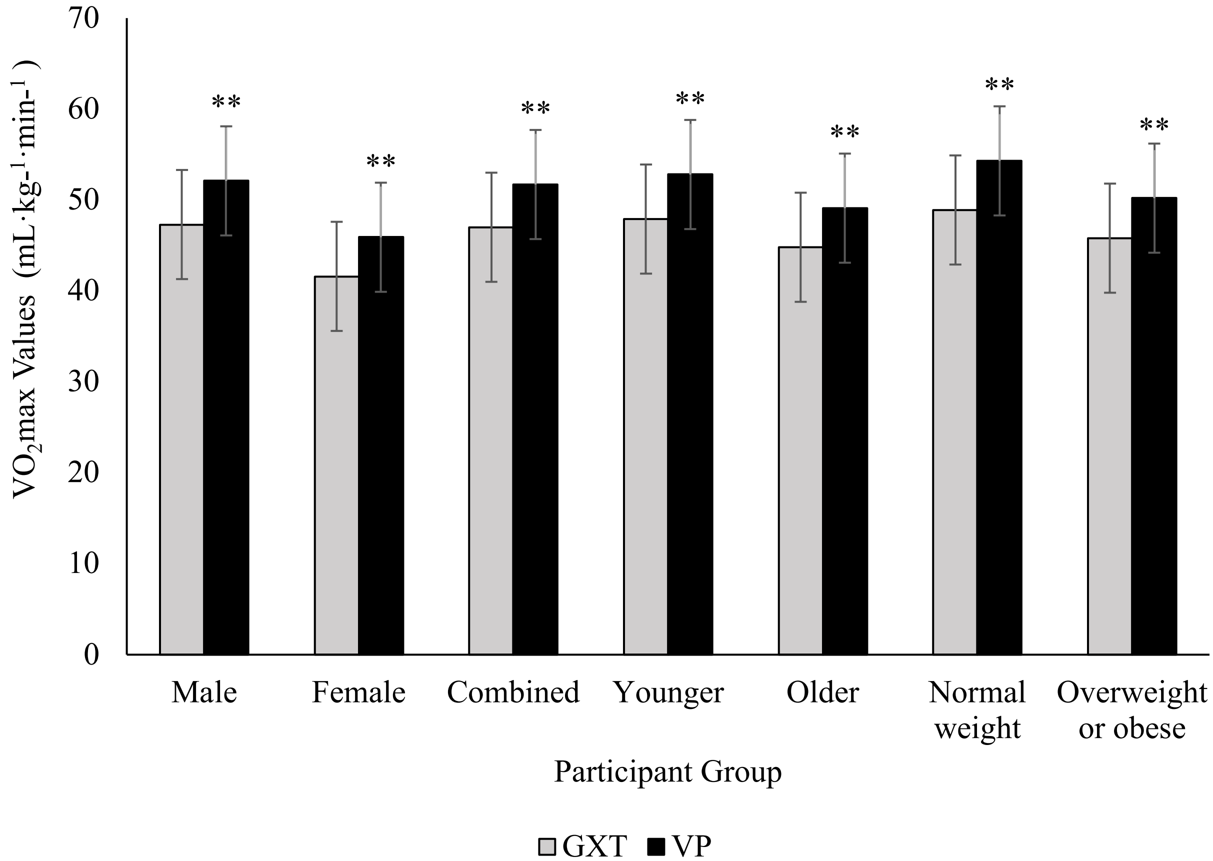
68.458, $p < 0.001$ (Table 9). Similar results were found regardless of sex, age group or BMI group (Figure 1). All of which obtained significantly greater VO_2max values upon completion of the VP compared to during the incremental to maximal GXT (Figure 1).

Table 9. Oxygen consumption values collected from 3,366 study I participants during the incremental to maximal graded exercise test and subsequent verification phase.

Variable	n	VO_2, ml·kg^{-1}·min^{-1}		Δ	P value
		GXT	VP		
Sex,					
Male	3155	47.3 ± 6.0	52.1 ± 6.7	4.8 ± 4.0	**<0.001****
Female	211	41.6 ± 5.3	45.9 ± 6.4	4.3 ± 4.0	**<0.001****
Combined	3366	47.0 ± 6.1	51.7 ± 6.8	4.7 ± 4.0	**<0.001****
Age group,					
Younger (< 30 yr)	2364	47.9 ± 5.9	52.8 ± 6.7	4.9 ± 4.1	**<0.001****
Older (≥ 30 yr)	1002	44.8 ± 6.1	49.1 ± 6.5	4.3 ± 3.7	**<0.001****
BMI group,					
Normal weight (< 25.0 kg/m^2)	1266	48.9 ± 6.0	54.3 ± 6.6	5.3 ± 4.4	**<0.001****
Overweight or obese (≥ 25.0 kg/m^2)	2100	45.8 ± 5.9	50.2 ± 6.5	4.4 ± 3.7	**<0.001****

Values are presented as mean ± standard deviation unless otherwise stated.
VO_2 = Oxygen consumption, GXT = Graded exercise test, VP = Verification phase, BMI = Body mass index
Note: Paired-samples t-tests were used to determine if there were significant mean differences in VO_2 values between GXT and VP.
**$p < 0.001$.

Figure 1. VO_2max values of study I participants measured during the graded exercise test (GXT) and subsequent verification phase (VP).



*Denotes a statistically significant difference between GXT and VP, $p < 0.001$.

2.4.3. Aerobic fitness standard for structural firefighters

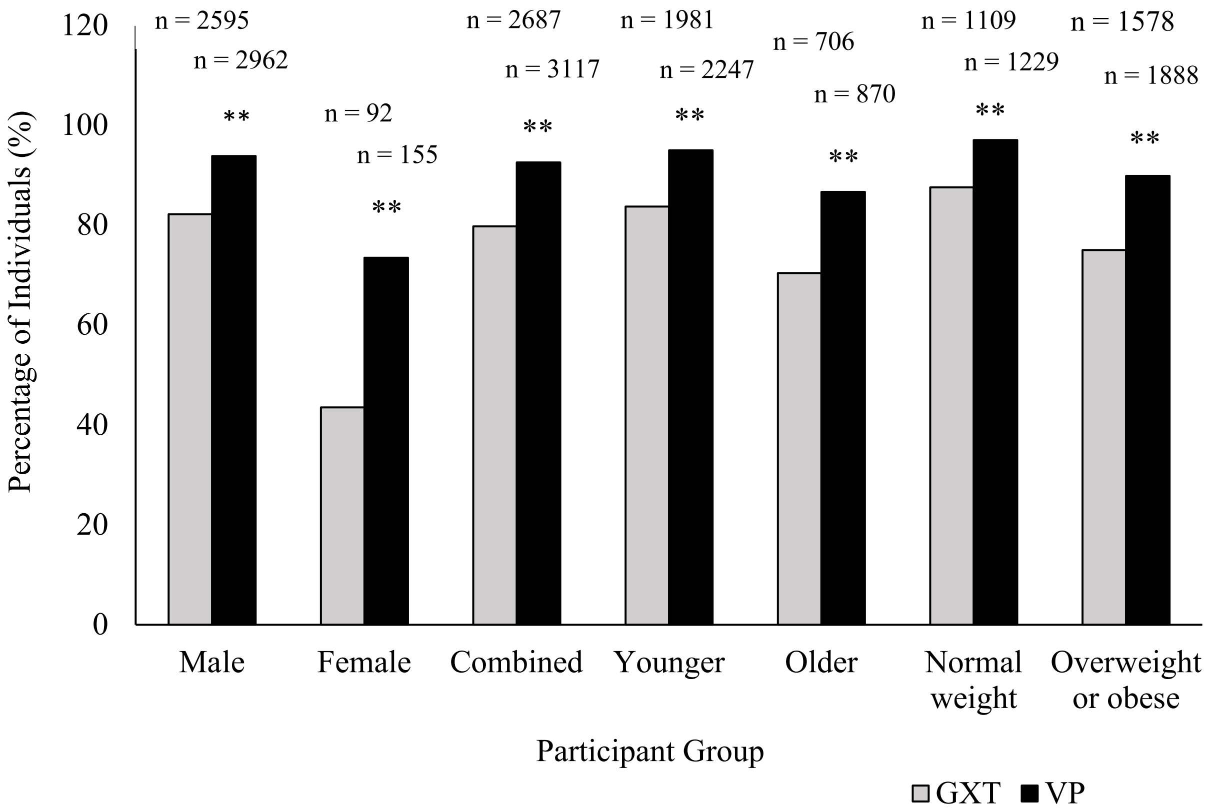
Finally, the proportion of participants who met the aerobic fitness standard for structural firefighters during the incremental to maximal GXT was compared to the proportion of participants who met the aerobic fitness standard for structural firefighters during the VP (Table 10). A significantly greater proportion of participants were able to meet the aerobic fitness standards for structural firefighters after completing the VP (92.6%) compared to during the incremental to maximal GXT (79.8%). In fact, 430 (12.8%) participants were able to meet the aerobic fitness standard for structural firefighters after completing the VP after failing to meet it during the incremental to maximal GXT ($p < 0.001$). Similar significant differences were found regardless of the study participants' sex, age group or BMI group (Figure 2). A significantly greater proportion of both males and females were able to meet the aerobic fitness standard for structural firefighters after completing the VP (93.9% and 73.5% respectively) compared to during the incremental to maximal GXT (82.3% and 43.6%, respectively). In fact, 367 (11.6%) males and 63 (29.9%) females were able to meet the aerobic fitness standard for structural firefighters after completing the VP after failing to meet it during the incremental to maximal GXT ($p < 0.001$). A significantly greater proportion of both younger and older participants were able to meet the aerobic fitness standard for structural firefighters after completing the VP (95.1% and 86.8% respectively) compared to during the incremental to maximal GXT (83.8% and 70.5%, respectively). In fact, 266 (11.3%) younger and 164 (16.3%) older participants were able to meet the aerobic fitness standard for structural firefighters after completing the VP after failing to meet it during the incremental to maximal GXT ($p < 0.001$). Finally, a significantly greater proportion of both normal weight and overweight or obese participants were able to meet the aerobic fitness standard for structural firefighters after completing the VP (97.1% and 89.9% respectively) compared to during the incremental to maximal GXT (87.6% and 75.1%, respectively). In total, 120 (9.5%) normal weight and 310 (14.8%) overweight or obese participants were able to meet the aerobic fitness standard for structural firefighters after completing the VP after failing to meet it during the incremental to maximal GXT ($p < .001$).

Table 10. The number and percentage of study I participants who met the aerobic fitness standard for structural firefighters during the incremental to maximal graded exercise test and during the verification phase.

	n	GXT	VP	Δ	p
Sex,					
Male	3155	2595 (82.3)	2962 (93.9)	367 (11.6)	**<0.001****
Female	211	92 (43.6)	155 (73.5)	63 (29.9)	**<0.001****
Combined	3366	2687 (79.8)	3117 (92.6)	430 (12.8)	**<0.001****
Age group,					
Younger (< 30 years)	2364	1981 (83.8)	2247 (95.1)	266 (11.3)	**<0.001****
Older (≥ 30 years)	1002	706 (70.5)	870 (86.8)	164 (16.3)	**<0.001****
BMI group,					
Normal weight (< 25.0 kg/m^2)	1266	1109 (87.6)	1229 (97.1)	120 (9.5)	**<0.001****
Overweight or obese (≥ 25.0 kg/m^2)	2100	1578 (75.1)	1888 (89.9)	310 (14.8)	**<0.001****

Values are presented as frequencies, n (%).
GXT = Graded exercise test, VP = Verification phase, BMI = Body mass index
Note: The proportion of individuals who met the aerobic fitness standard during the GXT was compared to that of those who met the aerobic fitness standard during the VP using a McNemar test with continuity correction.
**p < 0.001.

Figure 2. Percentage of study I participants who met the aerobic fitness standard for structural firefighters during the incremental to maximal graded exercise test (GXT) and subsequent verification phase (VP).



**Denotes a statistically significant difference between GXT and VP, $p < 0.001$.

2.5. DISCUSSION

The results of this study indicate that most study participants are not able to attain their VO_2max, as confirmed by the presence of a VO_2 plateau, during an incremental to maximal GXT. Only 1,096 (24.6%) of the study participants attained their VO_2max during the incremental to maximal GXT before reaching volitional fatigue. This finding is consistent with other research regarding the attainment of a VO_2max during an incremental to maximal exercise testing protocol. Draper, Wood & Fallowfield (2003) noted that an oxygen plateau occurs in less than 33% of physically healthy and active adolescent and adult males when using continuous incremental to maximal intensity exercise protocols performed to volitional exhaustion. Contrary to these results, other studies have demonstrated that a VO_2 plateau can be detected in anywhere from 17-100% of subjects tested (Astorino et al., 2000). The most important factors impacting the incidence of a VO_2 plateau are age (Astorino et al., 2005), testing modality (Gordon et al., 2012), and data analysis methodology (Astorino, 2009). Astorino et al., (2005) demonstrated that the strongest predictor of VO_2 plateau incidence was age and not training status, body composition or training history. In contrast to their findings, our study found no significant difference in age between those who attained their VO_2max during the incremental to maximal GXT (27.6 $\pm$ 6.0 yr) and those who did not (27.4 $\pm$ 5.9 yr). There were also no significant differences in any of the other descriptive characteristics (e.g., sex, height, body mass or BMI) between the two groups. Gordon et al., (2012) demonstrated that treadmill testing elicited a VO_2 plateau in 58% of study participants. This percentage is significantly higher than the percentage we found in our study (24.6%). However, they used an incremental to maximal ramp test and increased the treadmill intensity at a rate of 0.5% every 30-s while maintaining a constant running speed of 10 km/h. Our incremental to maximal GXT protocol used "step" increases in exercise intensity which each lasted 2 minutes in duration. In addition, Gordon et al., (2012) used a VO_2 plateau criterion of $\leq$ 50 $mL \cdot min^{-1,}$ whereas our study used the more commonly accepted criterion of $\leq$ 150 $mL \cdot min^{-1}$.

In the present study, most study participants were only able to attain a VO_2peak during the incremental to maximal GXT before reaching volitional fatigue and required a VP to attain their VO_2max. 3,366 (75.4%) participants could not attain their VO_2max during the incremental to maximal GXT before reaching volitional fatigue. These individuals were only able to attain VO_2peak values (47.0 $\pm$ 6.1 $mL \cdot kg^{-1} \cdot min^{-1}$) and would require one or more verification workload(s) to attain their VO_2max (51.7 $\pm$ 6.8 $mL \cdot kg^{-1} \cdot min^{-1}$). This is similar to the results found in other studies where a VO_2 plateau became apparent in "every" subject when using a series of non-continuous, progressively-increasing, constant work rate tests (Taylor, Buskirk & Henschel, 1955; Mitchell, Sproule & Chapman, 1957; Snell et al., 2007). Several hypotheses exist as to why these individuals could not attain their VO_2max during the incremental to maximal GXT to volitional fatigue. One explanation is that since these individuals are not trained athletes, they may have a lower pain and fatigue tolerance than fit individuals. If this were the case, the physical pain or exhaustion experienced during the incremental to maximal GXT might cause them to terminate the exercise with no evident VO_2 plateau (Wagner, 2000). In addition, these individuals might not possess the work tolerance necessary to work long enough and hard enough to sufficiently tax their aerobic energy system before reaching muscular fatigue/exhaustion. Individuals can recover between increasingly difficult workloads by performing one or more verification workloads separated by active rest periods. This may allow their muscles to recover to perform increasingly difficult workloads and reach their VO_2max.

Very importantly, a significantly higher proportion of participants met the job-related aerobic fitness standard for structural firefighters after completing the VP compared to during the incremental to maximal GXT. In total, 430 (12.8%) participants were able to meet the job-related aerobic fitness standard for structural firefighters after completing the VP, although they failed to meet the standard during the incremental to maximal GXT ($p < .001$). These findings remain consistent regardless of sex, age group or BMI group. Females, older participants and overweight or obese participants received the greatest benefit from completing a VP. 29.9% of female participants, 16.3% of older participants and 14.8% of overweight or obese participants were able to meet the job-related aerobic fitness standard during the VP after failing to meet it during the

GXT. This is likely because the study participants within these subgroups typically have lower VO2max values than their counterparts and were significantly closer to the aerobic fitness standard for structural firefighters. On average, females have a VO_2max value of about 70-75% of males (Kenney, Wilmore & Costill, 2012). VO_2max generally decreases gradually with age, with a rate of decline of about 10% per decade after the age of 25 years (Astrand, 1960), and increases in BMI lead to decreases in VO_2max (Gosh & Jahan, 2017). In this study, females, older individuals and overweight or obese individuals had mean VO_2max values of 45.9 ± 6.4 $mL \cdot kg^{-1} \cdot min^{-1}$, 49.1 ± 6.5 $mL \cdot kg^{-1} \cdot min^{-1}$ and 50.2 ± 6.5 $mL \cdot kg^{-1} \cdot min^{-1}$ respectively. All of which were significantly less than the VO_2max values of men, younger individuals and normal-weight individuals whose mean VO_2max values were 52.1 ± 6.7 $mL \cdot kg^{-1} \cdot min^{-1}$, 52.8 ± 6.7 $mL \cdot kg^{-1} \cdot min^{-1}$ and 54.3 ± 6.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. That is, females, older individuals, and overweight or obese individuals are most likely to benefit from the use of a VP because it allows them the opportunity to reach their VO_2max, which may enable them to meet the aerobic fitness standard instead of just their VO_2peak, which may not meet the aerobic fitness standard. By implementing a VP immediately following the incremental to maximal GXT, 75.4% of study participants could attain their VO_2max, as verified by the presence of a VO_2 plateau, and not just their VO_2peak. Therefore, conclusions about their aerobic fitness could be made on the more accurate VO_2max values and not just their VO_2peak values.

2.6. CONCLUSION

In conclusion, study participants should complete a VP immediately following an incremental to maximal GXT performed to volitional fatigue to accurately measure their VO_2max and not just a VO_2 peak. This is especially important for structural firefighter applicants whose results from their aerobic fitness tests are used to determine whether or not they meet the job-related aerobic fitness standard required to be hired as a front-line worker. The present study shows that using a VP immediately after an incremental to maximal GXT to volitional fatigue significantly increases the proportion of individuals who meet the job-related aerobic fitness standard for structural firefighters. This is especially important for females, older individuals and overweight or obese individuals whose mean VO_2max scores are significantly lower compared to their counterparts and are much closer to the aerobic fitness standard for structural firefighters. This makes sense, as the aerobic fitness standard for structural firefighters is based on the aerobic fitness levels of specific subgroups of individuals, usually females and older individuals, who can complete the most physically demanding and frequently occurring job tasks safely and efficiently. The findings of this study are also applicable to any situation in which repeated measurements of VO_2max are taken to establish the efficacy of a training stimulus/physical activity intervention or the impact of pharmaceutical interventions on sport-related or occupational physiological fitness.

CHAPTER 3: MANUSCRIPT II

Using firefighter applicants' aerobic fitness and select physical characteristics to predict their simulated job task completion times and performance scores.

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3.1. OVERVIEW

The aerobic fitness (VO_2max) and musculoskeletal mobility, flexibility, strength, power and endurance of firefighter applicants are commonly assessed using aerobic fitness tests and critical work-related job tests. Critical work-related job tests usually include several tasks designed to simulate the physical demands of the actual on-the-job emergency tasks. To be hired, firefighter applicants must be able to safely and efficiently complete these critical job simulation tasks within a given time. Many studies have been published to determine the relationship between various aspects of fitness and firefighting job performance. However, these studies have failed to explore the relationships between the individuals' physiological and physical characteristics and their ability to meet the time completion standards for each simulated job task. A better understanding of the physiological and physical characteristics of firefighting performance would enable firefighter applicants to better prepare for and meet the time completion standards required in each simulated job task.

This study aims to examine the relationships between the participants' aerobic fitness (VO_2max), select physical characteristics (e.g. sex, age, height, body mass and body mass index (BMI)), simulated job task completion times (seconds), and performance scores (meets standards or does not meet standards) in structural firefighter applicants undergoing the Structural Firefighter Fitness Assessment (SFFA). 1902 (1133 male and 769 female) structural firefighter applicants completed an aerobic fitness test and several standardized simulated job tasks (e.g. hose carry, rope pull, hose advance, ladder lift, victim drag, forced entry). Independent-samples t-tests were run to determine differences in participant characteristics and simulated job task completion times between sexes. In addition, independent-samples t-tests were run to determine any significant differences in physical characteristics and aerobic fitness measures between those participants who met the overall simulated job task fitness standard and those who did not. Chi-square tests for homogeneity were performed between sexes to determine if there were significant differences in the proportion of participants to meet the overall simulated job task fitness standard and individual simulated job task completion time standards. Pearson's product-moment correlations were run to assess the relationships between participants' aerobic fitness, select physical characteristics, and simulated job task completion times. Several separate binomial logistic regression analyses were conducted to predict individual and overall simulated job task performance scores. Multiple regression analyses were also conducted to predict individual simulated job task completion times. The male participants had significantly faster completion times for each simulated job task than the female participants, $p < 0.001$. A significantly greater proportion of the male participants met each simulated job task performance standard and the overall job-related fitness test standard, $p < 0.001$. VO_2max, height, and body mass all had significant negative regression weights on all simulated job task completion times, $p < 0.05$. Firefighter applicants must strive to find the right balance between select physical characteristics, aerobic fitness training, and musculoskeletal fitness training to meet the required job-related fitness test standards and be hired.

3.2. INTRODUCTION

Firefighting is widely accepted as one of the most physically demanding and dangerous civilian occupations (Michaelides et al., 2008; Bahrke, 1982; Brownlie et al., 1985; Davis, Dotson & Santa Maria, 1982). Under emergency circumstances, firefighters must lift and carry heavy equipment while wearing cumbersome personal protective equipment (PPE) in high ambient temperatures. Therefore, firefighters must possess a level of fitness that allows them to perform the most frequently occurring and physically demanding on-the-job tasks safely and efficiently. It is well documented that firefighter job performance is positively associated with increased levels of physical fitness (Davis & Dotson, 1987; Davis, Dotson & Santa Maria, 1982; Lusa et al., 1993; Rhea, Alvar & Gray, 2004; Williford et al., 1999). Aerobic and musculoskeletal fitness are important factors when considering the overall performance of a firefighter for their job (Michaelides et al., 2008). Therefore, these aspects of fitness are commonly assessed in both firefighter candidates and returning-to-work incumbents as part of a more comprehensive physical fitness assessment (e.g. Structural Firefighter Fitness Assessment (SFFA)) to ensure that they can meet the job demands.

Aerobic fitness is most commonly measured during an incremental to maximal graded exercise test (GXT) performed to volitional fatigue and is best represented by an individual's maximal oxygen consumption (VO_2max). Gledhill and Jamnik (1992) found that the most physically demanding firefighting tasks require an average VO_2max of 41.5 $mL \cdot kg^{-1} \cdot min^{-1}$. Therefore, they proposed that firefighters develop and maintain a VO_2max greater than 45.0 $mL \cdot kg^{-1} \cdot min^{-1}$. This ensures that firefighters can safely and efficiently perform the most frequently occurring and physically demanding on-the-job tasks while maintaining an 8-10% reserve capacity required in emergencies. Subsequently, in response to a 1999 Supreme Court of Canada Decision, hereafter referred to as the Meiorin Decision (Supreme Court of Canada, 1999), they revised the minimum acceptable VO_2max for firefighter applicants to 42.5 $mL \cdot kg^{-1} \cdot min^{-1}$ to ensure that the standards were not discriminatory to incumbent firefighters who were females (of all ages) and males over the age of 50 years.

On the other hand, firefighter applicants' job-specific musculoskeletal mobility, flexibility, power, strength and endurance are most commonly assessed using job-related tests. These tests include several tasks designed to simulate the physical demands of the actual on-the-job tasks (e.g., hose carry, rope pull, hose advance, ladder lift, victim drag, and forced entry). Firefighter applicants and returning-to-work incumbents must be able to complete these simulated on-the-job tasks within a given time, safely and efficiently, to be hired. Numerous studies have been published to determine the relationship between various aspects of fitness and firefighting job performance (Davis, Dotson & Santa Maria, 1982; Michaelides et al., 2008; Rhea, Alvar & Gray, 2004; Williford et al., 1999). For example, previous research has shown a significant negative correlation between upper-body strength/endurance and simulated job task completion times (Davis & Dotson, 1987; Michaelides et al., 2008; Rhea, Alvar & Gray, 2004; Williford et al., 1999). However, these studies have failed to explore the relationships between the individuals' physical and physiological characteristics and their ability to meet the time completion standards for each simulated job task as well as the overall job-related work test standard (i.e., meets the standard or does not meet the standard). A better understanding of the physical and physiological characteristics of firefighting performance would enable firefighter applicants to better prepare for and meet the standards required for each simulated job task and overall job-related work test. Therefore, this study examined the relationships between the participants' aerobic fitness, select physical characteristics, simulated job task completion times, and performance scores in structural firefighter applicants undergoing the SFFA.

The goals of this study were to 1) determine the number and proportion of participants to complete each simulated job task and the related mean completion times, 2) determine the number and proportion of participants to meet both the overall and each simulated job task performance standard, 3) determine the sex, age, height, body mass, body mass index (BMI) and aerobic fitness of those participants who did and did not meet the overall simulated job test performance standard, 4) identify the relationships between select physical characteristics, aerobic fitness and individual simulated job task completion times, 5) develop logistic regression models to predict individual simulated job task performance scores based on the participants' select physical characteristics and aerobic fitness, and 6) develop equations to predict individual simulated job task completion times based on the participants' select physical characteristics and aerobic fitness.

It was hypothesized that a more significant proportion of male participants would meet both the overall and each simulated job task performance standard, and their completion times would be significantly faster than that of female participants. The individuals' select physical characteristics and aerobic fitness would significantly correlate with individual simulated job task completion times and performance scores. Further, height, body mass and aerobic fitness would all negatively correlate with simulated job task completion times and positively correlate with the participant's ability to meet the performance standards. Finally, it was hypothesized that age would not significantly affect simulated job task completion times and performance scores.

3.3. METHODS

3.3.1. Study participants

1902 (1133 male and 769 female) structural firefighter applicants completed an aerobic fitness test and several simulated job tasks as part of the more comprehensive SFFA protocol. Each participant provided written informed consent and agreed to have their data analyzed and reported in an anonymized group format in future research. This study was approved by the York University Human Participants Review Committee, whose research ethics guidelines follow the Canadian Tri-Council research ethics (Certificate #: E2019-236). Prior to the aerobic fitness test, each participant completed the Physical Activity Readiness Questionnaire (PAR-Q+) and, if necessary, the ePARmed-X+ (www.eparmedx.com) to ensure that they were cleared for unrestricted physical activity (i.e., moderate to maximal intensity exercise). In addition, qualified exercise professionals took pre-exercise blood pressure and heart rate measurements using the automated BpTRU blood pressure device (BpTRU Medical Devices Ltd., Coquitlam, BC, Canada). These pre-exercise measurements were used strictly to clear participants for unrestricted physical activity and were not included in the data analysis. Following the pre-exercise screening procedure, study participants had their sex, age, height, body mass, and BMI measured and collected. Height was measured without footwear using a wall-mounted stadiometer (Seca MPH07SH3 Mechanical Wall Mount Stadiometer, Germany) to the nearest 0.01 m. Body mass was measured wearing light clothing and no footwear using a digital floor scale (Seca 876 Digital Floor Scale, Germany) to the nearest 0.1 kg. BMI was calculated as body mass (kg) divided by height squared (m^2).

3.3.2. Aerobic fitness test

An incremental to maximal GXT (modified Astrand protocol) and verification phase (VP), if required, was employed on a motorized treadmill to measure each participant's VO_2max. Prior to the commencement of the test, participants were given a 3-5 min warm-up on the treadmill (3.5 mph and 2.0% incline). During that time, they were given detailed test instructions and allowed to familiarize themselves with the expired air collection apparatus.

3.3.3. Graded exercise test

Study participants completed several progressively more demanding 2-minute workloads during which cardiorespiratory measurements were collected over the final 30 seconds of each workload (e.g. the volume of expired gas, fractional concentration of oxygen (O_2) and fractional concentration of carbon dioxide (CO_2)). The first workload was performed at 5.0 mph, and the incline depended on the participant's body mass (i.e., if their body mass was < 75 kg, an incline of 2.0% was used, and if their body mass was > 75 kg, an incline of 4.0% was used). For each successive workload, the incline was kept constant. The speed was increased by 1.0 mph until a comfortable running pace (between 6.0 and 7.0 mph) was achieved based on each individual's running gait and biomechanics. Once their maximal speed was attained, the incline was increased by 2.0% every workload and speed was kept constant until VO_2max was reached, or they could not continue (i.e., volitional fatigue).

VO_2max values were considered valid only if a VO_2 plateau was attained (i.e., an increase in $VO_2 < 150$ $mL \cdot min^{-1}$ or < 2.5 $mL \cdot kg^{-1} \cdot min^{-1}$ between consecutive workloads despite an increase in intensity). If valid VO_2max values were attained, the individuals were instructed to perform a 3-5 min cool-down (3.5 mph and 2.0% incline).

3.3.4. Verification phase

If participants failed to attain their VO_2max during the incremental to maximal GXT, they were instructed to perform one or more discontinuous supramaximal verification workload(s) (VW) during the VP. These VW, separated by 2-minute active-rest periods (3.5 mph and 2.0% incline), were performed at the same speed as the incremental to maximal GXT but at progressively higher inclines (2.0% greater than that used during the last stage of the GXT). These VW were performed until a VO_2max was attained. The participants were instructed to complete a 3-5 min cool-down at 3.5 mph and 2.0% incline.

3.3.5. Simulated job tasks

Participants were given a 10-minute rest before attempting the simulated job tasks following the aerobic fitness test. The hose carry, rope pull, hose advance, victim drag, and forced entry simulated job tasks were completed individually, and participants were required to meet SFFA completion time standards. The ladder lift simulated job task was not timed and was scored on a pass-or-fail basis. Individuals who were unable to complete a simulated job task successfully or whose completion time was too slow were given one re-test opportunity of that job task during the testing session. The performance scores for each simulated job task (i.e., meets the standard or does not meet the standard) were based on individuals completing the simulated job tasks at a safe and efficient pace (i.e., no running was allowed). Participants were required to meet the SFFA completion time standards for each simulated job task to meet the overall work-related job test performance standard.

3.3.5.1. Hose carry. Participants were instructed to lift a bundle of tied hose (85 lb; 38.6 kg) from the floor level up and onto their preferred shoulder. They were then required to carry the bundle up and down a set of stairs two times for 50 ft. Time began when the participants bent to pick up the bundle of hose and ended when they reached the bottom of the stairs for the second time. Throughout this task, the individuals were required to wear a 32 lb weighted vest and 8 lb ankle weights to simulate PPE weight.

3.3.5.2. Rope pull. Using a rope, participants were required to hoist and lower the weight of a 50 ft section of hose plus nozzle (50 lb) up and down a total height of 65 ft two times. This was to be done in a hand-over-hand controlled motion, both up and down. The participants were not allowed to rest their arms on the railing or hoist the weight by moving their feet backwards. Timing began when the participants started to hoist the weight and ended when they finished lowering the weight to the floor for the second time. Throughout this task, the individuals were required to wear the simulated PPE.

3.3.5.3. Hose advance. Via a strap held over their shoulder, participants were required to apply a force of 135 lb or 600.51 Newtons (N) to reposition two sections of charged hose at a distance of 50 ft. Timing started when the front of the sled crossed the start line and finished when the rear of the sled crossed the finish line. Participants were always required to look straight ahead and not touch any walls or supports. Throughout this task, the individuals were required to wear the simulated PPE.

3.3.5.4. Ladder lift. Participants were required to remove and replace a standard 25.5 kg ladder from brackets mounted 1.93 m above the floor (the height of the brackets on fire trucks). Throughout this task, the individuals were required to wear the simulated PPE. This task was not timed and was scored on a pass-or-fail basis.

3.3.5.5. Victim drag. Participants were required to drag a 200 lb dummy by a handle behind its' neck a distance of 25 ft from the starting line and 25 ft back to the starting line, weaving in and out of traffic cones placed every eight ft. Timing began when the participants bent to lift the dummy and ended when they re-crossed the starting line and turned the dummy around to be ready for the next participant. Throughout this task, the individuals were required to wear the simulated PPE.

3.3.5.6. Forced entry. Participants were required to move a heavily weighted tire a total of 12 in by hitting the tire repeatedly with a ten lb sledgehammer until the tire moved far enough to contact a marker. The height of the table was the height of a door handle at which a sledgehammer or axe is usually swung while conducting a forced entry. Timing began when the participants took their first backswing and ended when the tire reached the marker. Throughout this task, the individuals were required to wear the simulated PPE.

3.3.6. Statistical analyses

Analyses were performed using IBM SPSS Statistics for Macintosh, version 27.0 (IBM Corp., Armonk, NY, USA) and a significance threshold of $p < 0.05$ was considered statistically significant. Descriptive characteristics (i.e., age, height, body mass and BMI), aerobic fitness (i.e.,

VO_2max) and simulated job task completion times (i.e., seconds) are presented as means $\pm$ standard deviation. Sex and simulated job task performance scores (i.e., meets the standard or does not meet the standard) are presented as frequencies, n (%). Independent-samples t-tests were run to determine differences in participant characteristics and simulated job task completion times between sexes. In addition, independent-samples t-tests were run to determine any significant differences in anthropometric characteristics and aerobic fitness measures between those participants who met the overall work-related job test standard and those who did not. Chi-square tests for homogeneity were performed to determine if there were significant differences in the proportion of participants who met the overall work-related job test standard and individual simulated job task completion time standards between the sexes. Pearson's product-moment correlations were run to assess the relationships between participants' aerobic fitness, select physical characteristics and simulated job task completion times. The strength of correlation (r) was < 0.1 "trivial", 0.10 – 0.30 "weak", 0.30 – 0.50 "moderate" and > 0.50 "strong" (Cohen, 1988). To predict individual and overall simulated job task performance scores (i.e., meets the standard or does not meet the standard), several separate binomial logistic regression analyses were conducted: one for each of the simulated job tasks and one for the overall simulated job task fitness score. Multiple regression analyses were conducted to predict individual simulated job task completion times: one for each of the timed simulated job tasks (dependent variable). The models included sex, age, height, body mass, BMI, and VO_2max as the independent variables for these regression analyses.

3.4. RESULTS

3.4.1. Descriptive characteristics

Table 11 presents the descriptive characteristics of the structural firefighter applicants who participated in this study. There were a total of 1902 study participants, 1133 (59.6%) males and 769 (40.4%) females. Independent-samples t-tests were run to determine if there were significant differences in descriptive characteristics between the sexes. Male participants (28.4 $\pm$ 6.3 yr) were significantly older than female participants (27.5 $\pm$ 6.5 yr), with a statistically significant difference of 0.9 yr (95% CI, 0.31 to 1.47), $t(1900) = 2.995$, $p = 0.003$. Male participants (1.80 $\pm$ 0.07 m) were significantly taller than female participants (1.68 $\pm$ 0.06 m), with a statistically significant difference of 0.12 m (95% CI, 0.11 to 0.12), $t(1900) = 37.682$, $p < 0.001$. Male participants (86.8 $\pm$ 12.7 kg) were significantly heavier than female participants (69.9 $\pm$ 9.9 kg), with a statistically significant difference of 17.0 kg (95% CI, 15.95 to 17.98), $t(1863.926) = 32.748$, $P < 0.001$. Male participants (26.8 $\pm$ 3.4 kg/m^2) had significantly larger BMI values than female participants (24.6 $\pm$ 3.0 kg/m^2), a statistically significant difference of 2.15 kg/m^2 (95% CI, 1.86 to 2.44), $t(1756.632) = 14.457$, $p < 0.001$. Male participants (50.3 $\pm$ 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$) had significantly higher VO_2max values than female participants (44.5 $\pm$ 5.4 $mL \cdot kg^{-1} \cdot min^{-1}$), a statistically significant difference of 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$ (95% CI, 5.20 to 6.31), $t(1857.037) = 20.278$, $p < 0.001$.

Table 11. Descriptive characteristics of study II participants.

	Females	Males	Combined
Sample size, n (%)	769 (40.4)	1133 (59.6)	1902 (100)
Age, yr	27.5 $\pm$ 6.5	**28.4 $\pm$ 6.3***	28.1 $\pm$ 6.4
Height, m	1.68 $\pm$ 0.06	**1.80 $\pm$ 0.07****	1.75 $\pm$ 0.09
Body mass, kg	69.9 $\pm$ 9.9	**86.8 $\pm$ 12.7****	80.0 $\pm$ 14.3
BMI, kg/m^2	24.6 $\pm$ 3.1	**26.8 $\pm$ 3.4****	25.9 $\pm$ 3.4
VO_2max, mL·kg^{-1}·min^{-1}	44.5 $\pm$ 5.4	**50.3 $\pm$ 6.9****	48.0 $\pm$ 7.0

Values are presented as mean $\pm$ standard deviation.
Note: Independent-samples t-tests were used to determine significant differences in descriptive characteristics between sexes.
*$p < 0.05$. ** $p < 0.001$.

3.4.2. Simulated job task completion times

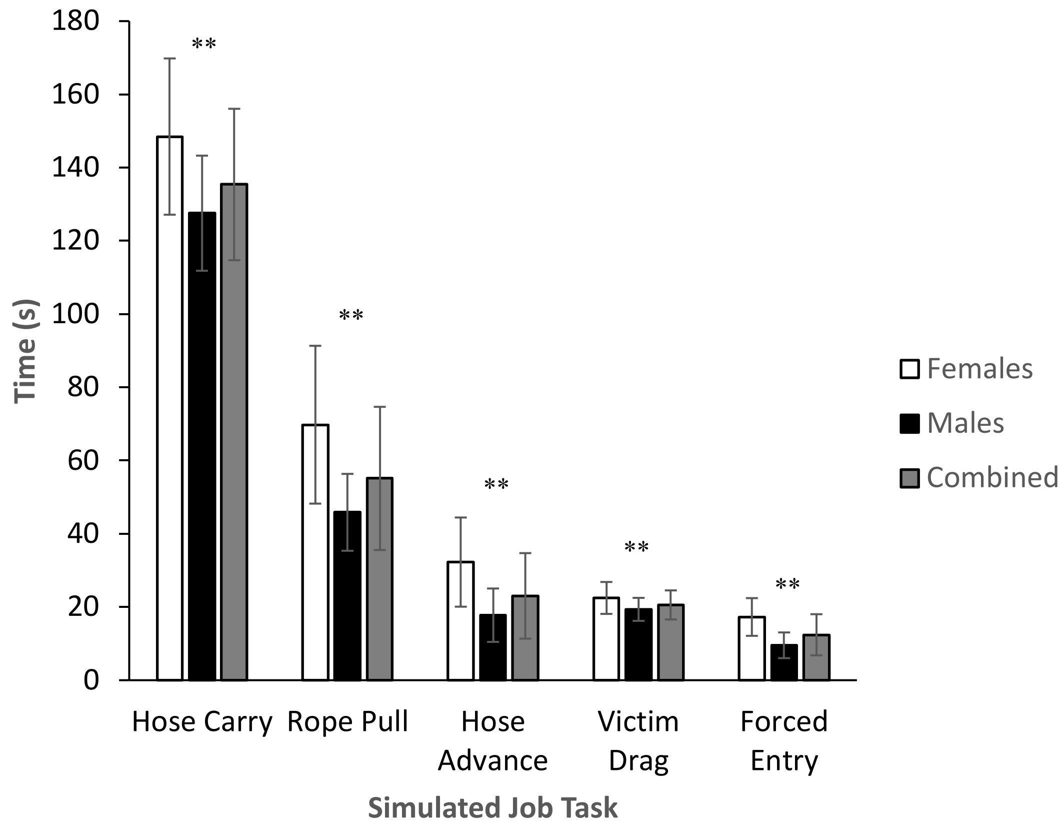
Table 12 presents the number and proportion of participants to complete each simulated job task and the related mean completion times. The completion times reported in Table 12 are derived from the completion times of participants who could complete each simulated job task regardless of how long it took them. Several Welch t-tests were run to determine if there were significant differences in the completion times between males and females due to the assumption of homogeneity of variances being violated, as assessed by Levene's test for equality of variances ($p < 0.001$). As assessed by inspection of the boxplots, there were no outliers in the data, and completion times for each sex were normally distributed for each simulated job task, as assessed by Shapiro-Wilk's test ($p < 0.05$). The male participants had significantly faster completion times for each simulated job task than the female participants (Figure 3).

Table 12. The number and proportion of study II participants to complete each simulated job task and the related mean completion times.

	Females	Males	Combined
Hose carry			
Completed, n (%)	668 (86.9)	1115 (98.4)	1783 (93.7)
Time, sec	148.45 ± 21.3	**127.5 ± 15.7****	135.4 ± 20.7
Rope pull			
Completed, n (%)	705 (91.7)	1120 (98.9)	1824 (95.9)
Time, sec	69.8 ± 21.6	**45.9 ± 10.5****	55.1 ± 19.6
Hose advance			
Completed, n (%)	635 (82.6)	1111 (98.6)	1746 (91.8)
Time, sec	32.3 ± 12.2	**17.8 ± 7.3****	23.0 ± 11.7
Ladder lift			
Completed, n (%)	638 (83.0)	1119 (98.8)	1757 (92.4)
Time, sec	n/a	n/a	n/a
Victim drag			
Completed, n (%)	708 (92.1)	1116 (98.5)	1824 (95.9)
Time, sec	22.5 ± 4.4	**19.4 ± 3.1****	20.6 ± 4.0
Forced entry			
Completed, n (%)	660 (85.8)	1113 (98.2)	1773 (93.2)
Time, sec	17.3 ± 5.2	**9.5 ± 3.5****	12.4 ± 5.6

Values are presented as mean ± standard deviation.
Note: Independent-samples t-tests were used to determine significant differences in completion times between sexes.
**p < 0.001.

Figure 3. Study II participants' mean completion times during each simulated job task.



**Denotes a statistically significant difference between males and females, $p < 0.001$.

3.4.2.1. Hose carry. 1115 (98.4%) male and 668 (86.9%) female participants successfully completed the hose carry simulated job task. Male participants had faster completion times (127.5 ± 15.7 sec) than female participants (148.5 ± 21.3 sec), a statistically significant difference of 20.9 sec (95% CI, 19.06 to 22.79), $t(1101.239) = 22.017$, $p < 0.001$.

3.4.2.2. Rope pull. 1120 (98.9%) male and 705 (91.7%) female participants successfully completed the rope pull simulated job task. Male participants had faster completion times (45.9 ± 10.5 sec) than female participants (69.8 ± 21.6 sec), a statistically significant difference of 23.9 sec (95% CI, 22.22 to 25.64), $t(917.354) = 27.496$, $p < 0.001$.

3.4.2.3. Hose advance. 1117 (98.6%) male and 650 (84.5%) female participants successfully completed the hose advance simulated job task. Male participants had faster completion times (18.2 $\pm$ 9.2 sec) than female participants (33.6 $\pm$ 21.5 sec), a statistically significant difference of 16.4 sec (95% CI, 14.68 to 18.17), $t(789.453) = 18.502$, $p < 0.001$.

3.4.2.4. Ladder lift. 1119 (98.8%) male and 638 (83.0%) female participants completed the ladder lift simulated job task. However, this task was marked on a pass/fail basis and was not timed. Participants met the performance standard for this simulated job task if they could successfully complete the task, regardless of how long it took them.

3.4.2.5. Victim drag. 1116 (98.5%) male and 708 (92.1%) female participants successfully completed the victim drag simulated job task. Male participants had faster completion times (19.4 $\pm$ 3.11 sec) than female participants (22.5 $\pm$ 4.4 sec), a statistically significant difference of 3.1 sec (95% CI, 2.74 to 3.49), $t(1168.695) = 16.479$, $p < 0.001$.

3.4.2.6. Forced entry. 1116 (98.5%) male and 699 (90.9%) female participants successfully completed the forced entry simulated job task. Male participants had faster completion times (9.6 $\pm$ 3.7 sec) than female participants (18.8 $\pm$ 8.8 sec), a statistically significant difference of 9.2 sec (95% CI, 8.48 to 9.86), $t(850.962) = 26.131$, $p < 0.001$.

3.4.3. Simulated job task performance scores

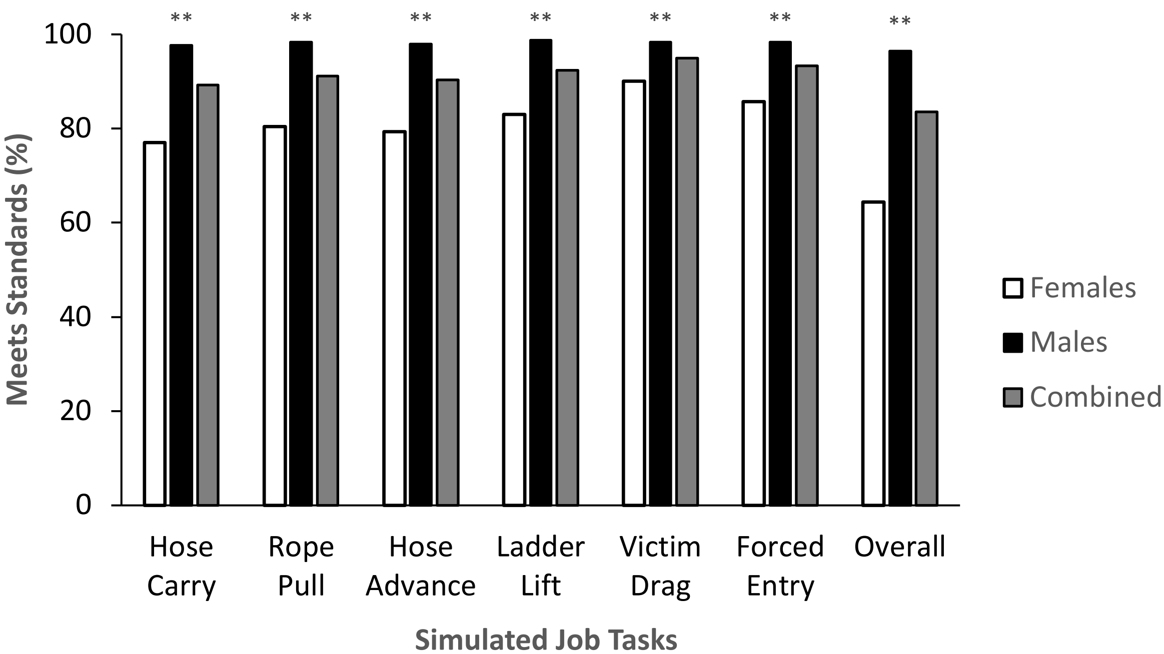
To compare the proportions of participants who met the completion time standards for each task between sexes, tests of two proportions were used. The test of two proportions used was the chi-square test for homogeneity (Table 13). A significantly greater proportion of the male participants met each simulated job task performance standard and the overall job-related fitness test standard (Figure 4).

Table 13. The number and proportion of study II participants who met both the overall and each simulated job task performance standard.

	Females	Males	Combined
Hose carry, n (%)	592 (77.0)	**1107 (97.7)****	1699 (89.3)
Rope pull, n (%)	618 (80.4)	**1115 (98.4)****	1733 (91.1)
Hose advance, n (%)	610 (79.3)	**1109 (97.9)****	1719 (90.4)
Ladder lift, n (%)	638 (83.0)	**1119 (98.8)****	1757 (92.4)
Victim drag, n (%)	692 (90.0)	**1115 (98.4)****	1807 (95.0)
Forced entry, n (%)	659 (85.7)	**1115 (98.4)****	1774 (93.3)
Overall, n (%)	495 (64.4)	**1093 (96.5)****	1588 (83.5)

Note: Chi-square tests for homogeneity were used to determine significant differences in the proportion of participants to meet the performance standards between sexes.
**$p < 0.001$.

Figure 4. The proportion of study II participants who successfully met the Structural Firefighter Fitness Assessment standards both overall and for each simulated job task.



**Denotes a statistically significant difference between males and females, $p < 0.001$.

3.4.3.1. Hose carry. For the hose carry simulated job task, 1699 (89.3%) of all participants met the performance time standard. 1107 (97.7%) male participants were able to meet the completion time standard compared to 592 (77.0%) female participants, a significant difference in proportions of 0.207, $p < 0.001$.

3.4.3.2. Rope pull. For the rope pull simulated job task, 1733 (91.1%) of all participants met the performance time standard. 1115 (98.4%) male participants were able to meet the performance time standard compared to 618 (80.4%) female participants, a significant difference in proportions of 0.180, $p < 0.001$.

3.4.3.3. Hose advance. For the hose advance simulated job task, 1719 (90.4%) of all participants met the performance time standard. 1109 (97.9%) male participants were able to meet the performance time standard compared to 610 (79.3%) female participants, a significant difference in proportions of 0.186, p < 0.001.

3.4.3.4. Ladder lift. For the ladder lift simulated job task, 1757 (92.4%) of all participants successfully completed the task. 1119 (98.8%) male participants were able to successfully complete the simulated job task compared to 638 (83.0%) female participants, a significant difference in proportions of 0.158, p < 0.001.

3.4.3.5. Victim drag. For the victim drag simulated job task, 1807 (95.0%) of all participants met the performance time standard. 1115 (98.4%) male participants were able to meet the completion time standard compared to 692 (90.0%) female participants, a significant difference in proportions of 0.084, p < 0.001.

3.4.3.6. Forced entry. For the forced entry simulated job task, 1774 (93.3%) of all participants met the performance time standard. 1115 (98.4%) male participants were able to meet the completion time standard compared to 659 (85.7%) female participants, a significant difference in proportions of 0.127, p < 0.001.

3.4.3.7. Overall job task fitness standard. 1588 (83.5%) of all participants met the overall performance time standards for all simulated job tasks. 1093 male participants (96.5%) met the completion time standards for every simulated job task compared to 495 (64.4%) female participants, a significant difference in proportions of 0.321, $p < 0.001$.

3.4.4. Descriptive statistics of the study participants who did and did not meet the overall performance standard for the simulated job tasks

The 1093 male participants who met the overall simulated job task standard were significantly taller and had higher VO_2max values than the 40 male participants who did not meet the standards ($p < 0.001$) (Table 14). The 495 female participants who met the overall job task standard were significantly taller, heavier, and had higher VO_2max values compared to the 274 female participants who did not meet the overall standard ($p < 0.001$) (Table 14). When the participants were combined, those who met the overall simulated job task standard were significantly taller, heavier, had greater BMI values, and had higher VO_2max values than those individuals who did not meet the standard ($p < 0.001$) (Table 14).

Table 14. Descriptive characteristics of the study II participants who did and did not meet the overall performance standards for the simulated job tasks.

	Females	Males	Combined
Did not meet the standard			
Sample size, n (%)	274 (35.6)	40 (3.5)	314 (16.5)
Age, yr	27.7 $\pm$ 7.2	30.1 $\pm$ 7.6	28.0 $\pm$ 7.3
Height, m	1.67 $\pm$ 0.06	1.75 $\pm$ 0.07	1.68 $\pm$ 0.07
Body mass, kg	67.8 $\pm$ 10.4	84.0 $\pm$ 16.9	69.8 $\pm$ 12.6
BMI, kg/m^2	24.4 $\pm$ 3.3	27.3 $\pm$ 4.9	24.7 $\pm$ 3.7
VO_2max, mL·kg^{-1}·min^{-1}	42.2 $\pm$ 5.5	42.4 $\pm$ 7.9	42.2 $\pm$ 5.9
Did meet the standard			
Sample size, n (%)	495 (64.4)	1093 (96.5)	1588 (83.5)
Age, yr	27.4 $\pm$ 6.0	28.4 $\pm$ 6.2	28.1 $\pm$ 6.2
Height, m	**1.69 $\pm$ 0.06****	**1.80 $\pm$ 0.07****	**1.77 $\pm$ 0.08****
Body mass, kg	**71.0 $\pm$ 9.4****	86.9 $\pm$ 12.5	**82.0 $\pm$ 13.7****
BMI, kg/m^2	24.7 $\pm$ 2.9	26.7 $\pm$ 3.3	**26.1 $\pm$ 3.3****
VO_2max, mL·kg^{-1}·min^{-1}	**45.8 $\pm$ 4.9****	**50.6 $\pm$ 6.7****	**49.1 $\pm$ 6.6****

Values are presented as mean $\pm$ standard deviation (SD)
BMI = Body mass index
Note: Independent-samples t-tests were run to determine differences between those participants who did and did not meet the overall performance standard.
**p < 0.001.

3.4.5. Intercorrelation between the descriptive characteristics of study participants and their simulated job task completion times

Pearson's product-moment correlations were run to assess the relationships between the participants' aerobic fitness (VO_2max), select physical characteristics (i.e., age, height, body mass, BMI, and VO_2max) and each simulated job task completion time (Table 15). Analyses showed the relationships to be linear between all variables, normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$), and there were no outliers. The coefficients ranged from -0.67 to 0.06, indicating relationships between the participants' aerobic fitness, select physical characteristics and their simulated job task completion times. Positive Pearson correlation coefficients indicated a positive correlation between the participants' aerobic fitness, select physical characteristics and simulated job task completion times, while negative Pearson correlation coefficients indicated a negative correlation. There were no medium or strong correlations between age and any simulated job task completion time ($r < 0.1$), except for the forced entry simulated job task. All other independent variables had statistically significant, moderate negative correlations with all simulated job task completion times (s), r = -0.67 to -0.21 ($p < 0.001$). For the rope pull simulated job task, height, body mass, and VO_2max demonstrated the highest negative correlations of -0.53, -0.50 and -0.64, respectively ($p < 0.001$). Sex had the greatest negative correlations with simulated job task completion times, r = -0.67 to -0.38 ($p < 0.001$).

Table 15. Intercorrelations between the study II participants' aerobic fitness, select physical characteristics and simulated job task completion times.

	Hose carry	Rope pull	Hose advance	Victim drag	Forced entry
Sample size, n (%)	1783(93.7)	1824(95.9)	1746(91.8)	1824(95.9)	1774(93.3)
Sex, m vs. f	**-0.49****	**-0.60****	**-0.60****	**-0.38****	**-0.67****
Age, yr	**0.05***	**-0.06***	**-0.08****	**0.06***	**-0.11****
Height, cm	**-0.42****	**-0.53****	**-0.57****	**-0.39****	**-0.56****
Body mass, kg	**-0.35****	**-0.50****	**-0.60****	**-0.34****	**-0.54****
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**-0.38****	**-0.33****	**-0.21****	**-0.28****	**-0.29****

*p < 0.05. **p < 0.001.

3.4.6. Binomial logistic regression models for predicting simulated job task performance scores

Several binomial logistic regressions were performed to ascertain the effects of sex, age, height, body mass and VO_2max on the likelihood that participants meet: 1) each simulated job task completion time standard and 2) the overall work-related job test performance standard.

3.4.6.1. Hose carry. In predicting hose carry performance scores, participants' height, body mass and VO_2max were shown to be statistically significant independent variables in the binomial regression model ($p < 0.05$ and $p < 0.001$) (Table 16). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 433.530$, $p < 0.001$. The model explained 41.3% (Nagelkerke R^2) of the variance in performance scores and correctly classified 90.5% of cases. Increases in height, body mass and VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 16. Logistic regression model predicting the likelihood of meeting the performance standard for the hose carry simulated job task based on sex, age, height, body mass and VO_2max.

Hose carry	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-20.58****	2.74	56.47	1	0.00		
Sex, m vs. f	0.51	0.31	2.78	1	1.67	0.92	3.03
Age, yr	-0.01	0.01	0.31	1	0.99	0.97	1.02
Height, cm	**0.05***	0.02	8.17	1	1.05	1.01	1.08
Body mass, kg	**0.05****	0.01	20.92	1	1.05	1.03	1.07
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**0.26****	0.02	145.45	1	1.29	1.24	1.35

*p < 0.05. **p < 0.001.

3.4.6.2. Rope pull. In predicting rope pull performance scores, participants' height, body mass and VO_2max were shown to be statistically significant independent variables in the binomial regression model ($p < 0.05$ and $p < 0.001$) (Table 17). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 354.261$, $p < 0.001$. The model explained 37.7% (Nagelkerke R^2) of the variance in performance scores and correctly classified 91.6% of cases. Increases in height, body mass and VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 17. Logistic regression model predicting the likelihood of meeting the performance standard for the rope pull simulated job task based on sex, age, height, body mass and VO_2max

Rope pull	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-20.32****	2.91	48.86	1	0.000		
Sex, m vs. f	0.28	0.34	0.69	1	1.32	0.68	2.56
Age, yr	0.02	0.01	1.44	1	1.02	0.99	1.05
Height, cm	**0.04***	0.02	5.52	1	1.04	1.01	1.08
Body mass, kg	**0.07****	0.01	36.74	1	1.07	1.05	1.10
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**0.23****	0.02	111.32	1	1.25	1.20	1.31

*p < 0.05. **p < 0.001.

3.4.6.3. Hose advance. In predicting performance scores for the hose advance simulated job task, participants' height, body mass and VO_2max were statistically significant independent variables in the binomial regression model (Table 18). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 390.425$, $p < 0.001$. The model explained 39.6% (Nagelkerke R^2) of the variance in performance scores and correctly classified 91.1% of cases. Increases in height, body mass and relative VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 18. Logistic regression model predicting the likelihood of meeting the performance standard for the hose advance simulated job task based on sex, age, height, body mass and VO_2max.

Hose advance	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-25.92****	2.96	76.72	1	0.000		
Sex, m vs. f	-0.35	0.32	1.23	1	0.71	0.38	1.31
Age, yr	0.00	0.01	0.06	1	1.00	0.98	1.03
Height, cm	**0.07****	0.02	17.76	1	1.07	1.04	1.11
Body mass, kg	**0.08****	0.01	48.76	1	1.09	1.06	1.11
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**0.23****	0.02	116.73	1	1.25	1.20	1.31

**p < 0.001.

3.4.6.4. Ladder lift. In predicting performance scores for the ladder lift simulated job task, participants' height, body mass and VO_2max were statistically significant independent variables in the binomial regression model (Table 19). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 313.179$, $p < 0.001$. The model explained 36.4% (Nagelkerke R^2) of the variance in performance scores and correctly classified 92.7% of cases. Increases in height, body mass and VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 19. Logistic regression model predicting the likelihood of meeting the performance standard for the ladder lift simulated job task based on sex, age, height, body mass and VO_2max.

Ladder lift	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-23.42****	3.10	57.02	1	0.00		
Sex, m vs. f	0.49	0.37	1.74	1	1.63	0.79	3.37
Age, yr	-0.01	0.01	0.14	1	0.99	0.97	1.02
Height, cm	**0.08****	0.02	18.59	1	1.08	1.04	1.12
Body mass, kg	**0.05****	0.01	16.08	1	1.05	1.03	1.07
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**0.21****	0.02	88.07	1	1.23	1.18	1.28

**p < 0.001.

3.4.6.5. Victim drag. In predicting performance scores for the victim drag simulated job task, participants' height, body mass and VO_2max were statistically significant independent variables in the binomial regression model (Table 20). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 184.763$, $p < 0.001$. The model explained 28.3% (Nagelkerke R^2) of the variance in performance scores and correctly classified 95.2% of cases. Increases in height, body mass and relative VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 20. Logistic regression model predicting the likelihood of meeting the performance standard for the victim drag simulated job task based on sex, age, height, body mass and VO_2max.

Victim Drag	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-17.81****	3.35	28.28	1	0.00		
Sex, m vs. f	-0.13	0.38	0.11	1	0.88	0.42	1.87
Age, yr	0.01	0.02	0.05	1	1.00	0.97	1.04
Height, cm	**0.04***	0.02	4.78	1	1.05	1.01	1.09
Body mass, kg	**0.04***	0.01	9.40	1	1.04	1.01	1.07
VO_2max, $mL{\cdot}kg^{-1}{\cdot}min^{-1}$	**0.23****	0.03	85.03	1	1.26	1.20	1.32

*p < 0.05. **p < 0.001.

3.4.6.6. Forced entry. In predicting performance scores for the forced entry simulated job task, participants' height, body mass, and VO_2max were statistically significant independent variables in the binomial regression model (Table 21). Sex and age were not statistically significant. This binomial logistic regression model was statistically significant, $X^2(5) = 234.872$, $p < 0.001$. The model explained 29.8% (Nagelkerke R^2) of the variance in performance scores and correctly classified 93.1% of cases. Increases in height, body mass and VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 21. Logistic regression model predicting the likelihood of meeting the performance standard for the forced entry simulated job task based on sex, age, height, body mass and VO_2max.

Forced entry	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-18.946****	3.05	38.69	1	0.00		
Sex, m vs. f	0.240	0.36	0.46	1	1.27	0.63	2.55
Age, yr	0.013	0.02	0.82	1	1.01	0.98	1.04
Height, cm	**0.053***	0.02	8.83	1	1.06	1.02	1.09
Body mass, kg	**0.041****	0.01	12.23	1	1.04	1.02	1.07
VO_2max, $mL{\cdot}kg^{-1}{\cdot}min^{-1}$	**0.199****	0.02	82.10	1	1.22	1.17	1.27

*p < 0.05. **p < 0.001.

3.4.6.7. Overall job task fitness score. In predicting performance scores for the overall simulated job tasks, participants' height, body mass and VO_2max were statistically significant independent variables in the binomial regression model (Table 22). Sex and age were not statistically significant independent variables. This binomial logistic regression model was statistically significant, $X^2(5) = 649.904$, $p < 0.001$. The model explained 48.9% (Nagelkerke R^2) of the variance in performance scores and correctly classified 87.4% of cases. Increases in height, body mass and VO_2max were all associated with an increased likelihood of meeting the performance time standard.

Table 22. Logistic regression model predicting the likelihood of meeting the overall performance standard based on sex, age, height, body mass and VO_2max.

Overall	*B*	SE	Wald	*df*	Odds ratio	95% CI for Odds ratio	
						LL	UL
Constant	**-26.504****	2.58	105.28	1	0.00		
Sex, m vs. f	0.030	0.26	0.01	1	1.03	0.62	1.72
Age, yr	0.005	0.01	0.19	1	1.01	0.98	1.03
Height, cm	**0.060****	0.01	17.86	1	1.06	1.03	1.09
Body mass, kg	**0.083****	0.01	67.71	1	1.09	1.07	1.12
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**0.255****	0.02	173.77	1	1.29	1.24	1.34

*p < 0.05. **p < 0.001.

3.4.7. Multiple regression models for predicting simulated job task completion times

Multiple regression models were run to predict the individual simulated job task completion times from sex, age, height, body mass and VO_2max as indicated below.

3.4.7.1. Hose carry. For the hose carry simulated job task, the multiple regression model significantly predicted completion times, $F(5, 1777) = 180.821$, $p < 0.001$, adj. $R^2 = 0.335$. All independent variables added significantly to the prediction, $p < 0.001$, except for age, which was not statistically significant. Sex, height, body mass and VO_2max had significant negative regression weights, indicating that as these variables increased the hose carry completion time decreased after controlling for the other variables in the model. Age did not significantly contribute to this model. Regression coefficients and standard errors are reported in Table 23.

Table 23. Multiple regression model predicting the completion times for the hose carry simulated job task based on sex, age, height, body mass and VO_2max.

Time	*B*	95% CI for *B*		SE	β	R^2	ΔR^2
		LL	UL				
Model						**0.34****	**0.34****
Constant	263.211**	240.36	286.06	11.65			
Sex, M vs. F	**-6.221****	-8.81	-3.64	1.32	**-0.15****		
Age, yr	0.099	-0.03	0.23	0.07	0.03		
Height, cm	**-0.258****	-0.40	-0.12	0.07	**-0.11****		
Body mass, kg	**-0.362****	-0.45	-0.27	0.05	**-0.25****		
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**-1.077****	-1.23	-0.92	0.08	**-0.35****		

Note. Model = “Enter” method in SPSS Statistics; B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE B = standard error of the coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2. **p < 0.001.

3.4.7.2. Rope pull. The multiple regression model significantly predicted completion times for the rope pull simulated job task, $F(5, 1819) = 297.659$, $p < 0.001$, adj. $R^2 = 0.448$. All independent variables added significantly to the prediction model, $p < 0.05$ and $p < 0.001$. These variables had significant and negative regression weights, indicating that as these variables increased, the predicted rope pull completion time decreased after controlling for the other variables in the model. Regression coefficients and standard errors are reported in Table 24.

Table 24. Multiple regression model predicting the completion times for the rope pull simulated job task based on sex, age, height, body mass and VO_2max.

Time	*B*	95% CI for *B*		SE	β	R^2	ΔR^2
		LL	UL				
Model						**0.45****	**0.45****
Constant	184.596	165.38	203.82	9.80			
Sex, M vs. F	**-8.511****	-10.71	-6.31	1.12	**-0.21****		
Age, yr	**-0.138***	-0.25	-0.03	0.06	**-0.04***		
Height, cm	**-0.248****	-0.37	-0.13	0.06	**-0.11****		
Body mass, kg	**-0.466****	-0.54	-0.39	0.04	**-0.34****		
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**-0.818****	-0.95	-0.69	0.07	**-0.28****		

Note. Model = "Enter" method in SPSS Statistics; B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE = standard error of the coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2.
*$p < 0.05$. **$p < 0.001$.

3.4.7.3. Hose advance. For the hose advance simulated job task, the multiple regression model significantly predicted completion times, $F(5, 1740) = 333.487$, $p < 0.001$, adj. $R^2 = 0.559$. All independent variables added significantly to the prediction model, $p < 0.05$ and $p < 0.001$ except for age. Age did not significantly contribute to this model. These variables had significant and negative regression weights, indicating that as these variables increased, the hose advance completion time decreased after controlling for the other variables in the model. Regression coefficients and standard errors are reported in Table 25.

Table 25. Multiple regression model predicting the completion times for the hose advance simulated job task based on sex, age, height, body mass and VO_2max.

Time	*B*	95% CI for *B*		SE	β	R^2	ΔR^2
		LL	UL				
Model						**0.49****	**0.49****
Constant	102.270	90.83	113.71	5.83			
Sex, M vs. F	**-4.721****	-6.01	-3.43	0.66	**-0.20****		
Age, yr	-0.051	-0.12	0.01	0.03	-0.03		
Height, cm	**-0.158****	-0.23	-0.09	0.04	**-0.12****		
Body mass, kg	**-0.368****	-0.41	-0.32	0.02	**-0.44****		
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**-0.354****	-0.43	-0.28	0.04	**-0.20****		

Note. Model = "Enter" method in SPSS Statistics; B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE B = standard error of the coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2. *$p < 0.05$. **$p < 0.001$.

3.4.7.4. Victim drag. The multiple regression model significantly predicted completion times for the victim drag simulated job task, $F(5, 1818) = 115.028$, $p < 0.001$, adj. $R^2 = 0.238$. All independent variables added significantly to the prediction model, $p < 0.05$ and $p < 0.001$, except for sex. sex did not significantly contribute to this model. Height, body mass and VO_2max all had significant and negative regression weights. As these variables increased, the victim drag completion times decreased after controlling for the other variables in the model. On the other hand, age had a significant and positive regression weight, indicating that as age increased, the victim drag completion times also increased after controlling for the other variables in the model. Regression coefficients and standard errors are reported in Table 26.

Table 26. Multiple regression model predicting the completion times for the victim drag simulated job task based on sex, age, height, body mass and VO_2max.

Time	*B*	95% CI for *B*		SE	β	R^2	ΔR^2
		LL	UL				
Model						**0.24****	**0.24****
Constant	**44.685****	40.12	49.25	2.33			
Sex, M vs. F	-0.136	-0.66	0.39	0.27	-0.02		
Age, yr	**0.029***	0.00	0.06	0.01	**0.05***		
Height, cm	**-.058****	-0.09	-0.03	0.01	**-0.13****		
Body mass, kg	**-0.081****	-0.10	-0.06	0.01	**-0.29****		
VO_2max, $mL\cdot kg^{-1}\cdot min^{-1}$	**-0.168****	-0.20	-0.14	0.02	**-0.29****		

Note. Model = "Enter" method in SPSS Statistics; B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE B = standard error of the coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2. *$p < 0.05$. **$p < 0.001$.

3.4.7.5. Forced entry. The multiple regression model significantly predicted completion times for the forced entry simulated job task, $F(5, 1767) = 372.766$, $p < 0.001$, adj. $R^2 = 0.512$. All independent variables added significantly to the prediction model, $p < 0.05$ and $p < 0.001$. All independent variables had significant and negative regression weights, indicating that as these variables increased, the forced entry completion times decreased after controlling for the other variables in the model. Regression coefficients and standard errors are reported in Table 27.

Table 27. Multiple regression model predicting the completion times for the forced entry simulated job task based on sex, age, height, body mass and VO_2max.

Time	*B*	95% CI for *B*		SE	β	R^2	ΔR^2
		LL	UL				
Model						**0.51****	**0.51****
Constant	**47.245****	41.95	52.54	2.70			
Sex, M vs. F	**-4.075****	-4.68	-3.47	0.31	**-0.35****		
Age, yr	**-0.077****	-0.11	-.05	0.02	**-0.09****		
Height, cm	**-0.077****	-0.11	-0.04	-0.02	**-0.12****		
Body mass, kg	**-0.110****	-0.13	-0.09	0.01	**-0.28****		
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	**-0.159****	-0.19	-0.12	0.02	**-0.19****		

Note. Model = "Enter" method in SPSS Statistics; B = unstandardized regression coefficient; CI = confidence interval; LL = lower limit; UL = upper limit; SE B = standard error of the coefficient; β = standardized coefficient; R^2 = coefficient of determination; ΔR^2 = adjusted R^2. *$p < 0.05$. **$p < 0.001$.

3.5. DISCUSSION

Firefighting is a dangerous and physically demanding job that requires high levels of physical fitness to perform safely and efficiently (Ensari et al., 2017). Understanding the relationships between individual physical characteristics, aerobic fitness, and firefighter performance would enable firefighter applicants to properly prepare for the entry-level fitness assessment and provide them with a better opportunity to meet the fitness standards and be successful. Therefore, this study aimed to analyze the simulated job task completion times and performance scores of firefighter applicants who underwent the SFFA between 2016 and 2020. This study examined the associations between the participants' aerobic fitness, select physical characteristics, and simulated job task completion times/performance scores. It used them to derive predictive models for the simulated job task performance scores (i.e., meets the standard or does not meet the standard) and completion times. The simulated job tasks included in the SFFA are based on the most frequently occurring and physically demanding on-the-job tasks performed by firefighters during emergencies and are criterion-based, not characteristics-based. The completion time standards for the simulated job tasks were derived from the completion times of female and older male incumbents who could complete the tasks safely and efficiently (Jamnik, Gumienak & Gledhill, 2013). Therefore, the simulated job tasks component of the SFFA was developed consistent with the Meiorin Decision requirements (Supreme Court of Canada, 1999).

The physical characteristics of the study participants indicate that the male participants were significantly older, taller, and heavier than the female participants ($p < 0.001$). In addition, the male participants had significantly larger BMI and VO_2max values than the female participants ($p < 0.001$).

1093 (96.5%) of all male participants met the overall job-related fitness test standard. In contrast, only 495 (64.4%) female participants met the overall job-related fitness test standard. Significant disadvantages in height, body mass and aerobic fitness likely affected the female participants' significantly slower completion times and lower performance scores, as performing the simulated job tasks requires aerobic and musculoskeletal fitness. The physically demanding nature of firefighting is likely more difficult for females than males due to differences in size and strength (Janssen et al., 2000). Nonetheless, female firefighter applicants must be able to meet the same SFFA performance standards as male firefighter applicants to ensure that they can safely and efficiently perform the most frequently occurring and physically demanding job tasks without compromising their safety, the safety of other firefighters and those victims needing to be rescued (Jamnik, Gumienak & Gledhill, 2013).

Understanding the relationship between aerobic fitness, select physical characteristics and simulated job task completion times might give firefighter applicants a better understanding of what is required of them to meet the SFFA standards. Therefore, the aim was to determine the relationships between aerobic fitness, select physical characteristics and completion times for all simulated job tasks. First, being a male participant had the greatest association with decreased completion times for all simulated job tasks, with correlation coefficients ranging from -0.67 to -0.38. This was expected as male participants had faster completion times and better performance scores than female participants on all simulated job tasks and overall. This is supported by Misner, Plowman & Boileau's (1987) findings, which found that male participants significantly outperformed female participants on all their simulated job tasks. They suggested two possible reasons why females may score more poorly than males on occupationally related physical performance tests: 1) they have less experience in doing the type of things that job-related tests attempt to simulate (i.e., motor ability), and 2) they are generally smaller than men which makes it more difficult for them to move heavy objects and carry firefighting equipment.

Although age was significantly associated with simulated job task completion times ($p < 0.05$), the associations were weak. It was unclear whether or not these associations were positive or negative, $r = -0.11$ to 0.06.

Height and body mass had very similar moderate to strong significant and negative associations with all simulated job task completion times ($p < 0.001$), $r = -0.60$ to -0.34. This means that increases in height and body mass were associated with faster completion times on every simulated job task. Again, this is not surprising because when analyzed as a whole, the 1588 (83.5%) participants to meet the overall SFFA had significantly greater height and body mass values than those who did not meet the standards. Male participants who met the overall standard were significantly taller than male participants who did not meet the standard. Female participants who met the overall standard were significantly taller and had greater body mass values than female participants who did not. This is supported by Misner, Plowman and Boileau (1987), who also found that height and weight were moderately correlated with physical task performance times ($p < 0.01$).

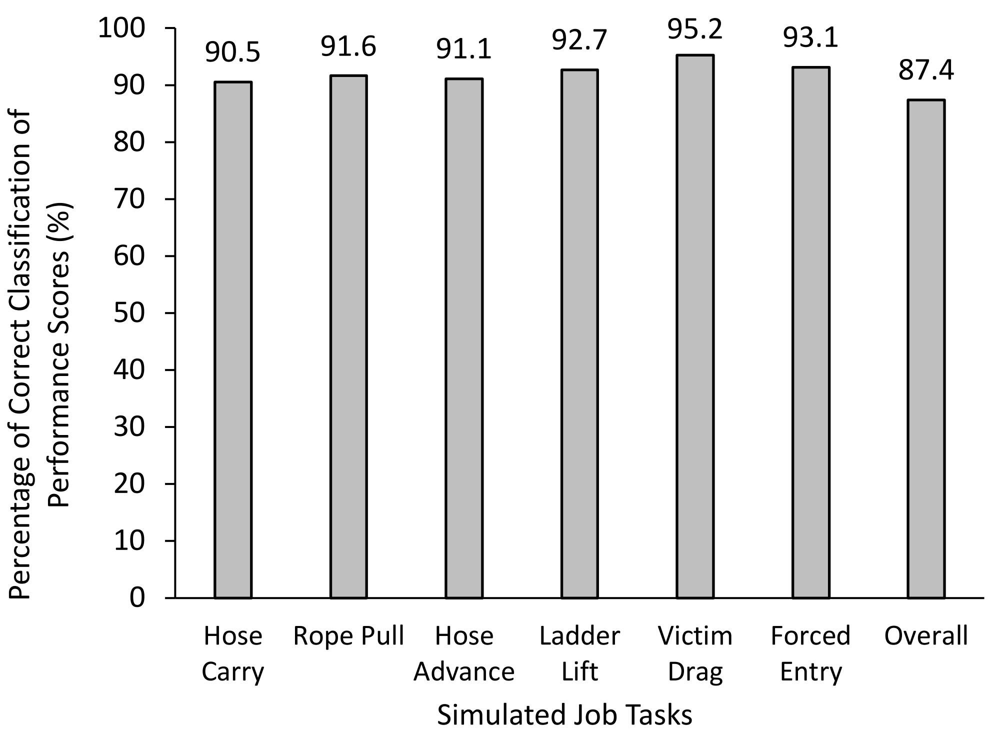
Finally, VO_2max had a moderate significant and negative association with all simulated job task completion times ($p < 0.001$), $r = -0.38$ to -0.21. This means that increases in aerobic fitness were associated with faster completion times on every simulated job task. This is axiomatic because individuals who met the overall fitness standard, both male and female, had significantly higher VO_2max values than those who did not meet the overall fitness standard ($p < 0.001$). These findings are supported by Nazari et al. (2018). They found that higher aerobic fitness levels were associated with faster performance times on both the hose drag and stair climb tasks with correlation coefficients of -0.30 and -0.31, respectively. These correlation coefficients correspond well with Myhre et al. (1997), who reported that performance on a firefighting rescue task was associated with higher cardiorespiratory fitness levels, $r = -0.36$. These findings are similar to those of Williams-Bell et al. (2009), who likewise found that VO_2max and body mass were significant predictors of simulated job task completion times.

This is not surprising, as higher VO_2max values are achieved through aerobic training in conjunction with strength training, resulting in better simulated job task completion times (Cantrell et al., 2014). It is also worth noting that relative VO_2max depends on body mass (e.g. $mL \cdot kg^{-1} \cdot min^{-1}$). Therefore, individuals can achieve higher relative VO_2max scores by having lower body mass values. This is relevant because female participants and those with smaller body mass values may achieve higher VO_2max scores during the incremental to maximal GXT but may not be able to meet the job-related fitness standards because of a lack of body mass and strength. This, in turn, relates to the greater overall strength required to perform the simulated job tasks successfully. On the other hand, participants with higher body mass values typically have lower VO_2max scores

(Dagan et al., 2013). However, they tend to meet the simulated job task performance standards more successfully.

Simple binomial logistic regression analyses were run to determine whether individuals' physical characteristics and aerobic fitness could predict performance scores (i.e., meets the standard or does not meet the standard) for each simulated job task and overall job-related fitness test. The binomial regression models correctly classified 87.4 to 95.2 percent of simulated job task performance scores based on sex, age, height, body mass and VO_2max (Figure 5). Height, body mass and VO_2max were all statistically significant ($p < 0.05$ and $p < 0.001$) independent variables in the multiple regression models and are significant predictors of successful performance outcomes.

Figure 5. Percentage of the correct classification of performance scores from sex, age, height, body mass and VO_2max for each of the simulated job task scores and the overall performance score.



Additionally, for each of the timed simulated job tasks, a multiple regression analysis was run to predict the completion times based on sex, age, height, body mass and VO_2max. Overall, sex had the greatest negative regression weight on simulated job task completion times. For each simulated job task except for the victim drag, male participants are predicted to have significantly faster completion times than female participants. Height, body mass and VO_2max also had significant negative regression weights on all simulated job tasks. However, their predictive weights, although significant, were less than that of sex. Therefore, taller, heavier individuals with higher VO_2max values tend to have faster completion times for each simulated job task. Based on these numerous multiple regression models, we can use the multiple regression equations in Table 28 to predict the mean expected completion times for each of the simulated job tasks of all persons in the population for any given set of independent variables (e.g. sex, age, height, body mass and VO_2max). Firefighter applicants can use these equations to predict their simulated job task completion times based on their sex, age, height, body mass and VO_2max and ensure that they are fully prepared for the entry-level/return to work fitness assessment.

Table 28. The multiple regression equations that can be used to predict the mean expected completion times for each of the timed simulated job tasks.

Simulated job task	Equation
Hose carry	Time (s) = 263.21 – (6.221 x sex) + (0.099 x age in yr) – (0.258 x height in cm) – (0.362 x body mass in kg) – (1.077 x VO_2max in $mL \cdot kg^{-1} \cdot min^{-1}$)
Rope pull	Time (s) = 184.596 – (8.511 x sex) - (-0.138 x age in yr) – (0.248 x height in cm) – (0.466 x body mass in kg) – (0.818 x VO_2max in $mL \cdot kg^{-1} \cdot min^{-1}$)
Hose advance	Time (s) = 102.270 – (4.721 x sex) - (0.051 x age in yr) – (0.158 x height in cm) – (0.368 x body mass in kg) – (0.354 x VO_2max in $mL \cdot kg^{-1} \cdot min^{-1}$)
Victim drag	Time (s) = 44.685 – (0.136 x sex) + (0.029 x age in yr) – (0.058 x height in cm) – (0.081 x body mass in kg) – (0.168 x VO_2max in $mL \cdot kg^{-1} \cdot min^{-1}$)
Forced entry	Time (s) = 47.245 – (4.075 x sex) - (0.077 x age in yr) – (0.077 x height in cm) – (0.110 x body mass in kg) – (0.159 x VO_2max in $mL \cdot kg^{-1} \cdot min^{-1}$)

Note: Females = 0 and Males = 1

3.6. CONCLUSION

This study examined the relationships between the aerobic fitness, select physical characteristics, simulated job task completion times, and performance scores in structural firefighter applicants. Male participants had significantly faster completion times for each simulated job task than female participants, and a greater proportion of them met the individual completion time standards plus overall job-related fitness test standards. Those participants who could meet the overall job-related fitness test standard were significantly taller and heavier than those who could not. In addition, successful participants had significantly higher VO_2max values than unsuccessful participants. Finally, sex, height, body mass and aerobic fitness were significantly and negatively correlated to simulated job task completion times and predictive of overall success in the job-related fitness test. Therefore, firefighter applicants must find the right balance between physical characteristics, aerobic training, and musculoskeletal training to meet the required job-related fitness test standards successfully. Firefighter applicants can use the multiple regression equations in this study to better prepare themselves for the SFFA. Based on their sex, age, height, body mass and VO_2max, applicants should be able to predict their individual simulated job task completion times/performance scores and overall performance score.

CHAPTER 4: MANUSCRIPT III

The effects of short-term detraining due to the COVID-19 Pandemic lockdowns on the aerobic fitness and simulated job task performance of firefighter applicants.

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4.1. OVERVIEW

Firefighters must possess the aerobic and musculoskeletal fitness required to perform the most physically demanding and frequently occurring on-the-job emergency tasks. As such, firefighter applicants generally undertake training programs to ensure that they meet the job-related aerobic and musculoskeletal fitness standards. However, the COVID-19 pandemic, and the numerous lockdowns associated with it, prevented many individuals from performing their regular training regimes. Therefore, the aims of this study were 1) to determine what effect the COVID-19 lockdowns had on the aerobic fitness and simulated job task performance of firefighter applicants and 2) to determine if there was a significant difference in the proportion of participants who met the overall job-related fitness standards before the COVID-19 pandemic compared to during the COVID-19 pandemic.

1718 (362 female and 1356 male) structural firefighter applicants completed an aerobic fitness test and several simulated firefighting job-related tasks before the COVID-19 pandemic. Also, 432 (71 female and 361 male) structural firefighter applicants completed an aerobic fitness test and the same simulated firefighting job-related tasks during the COVID-19 pandemic when lockdown restrictions were temporarily lifted. Their test outcomes were compared using individual

t-tests and chi-square tests for homogeneity. Participants who completed the aerobic fitness test during the COVID-19 pandemic had significantly lower VO_2max scores than those who completed the aerobic fitness test before the COVID-19 pandemic ($p < 0.001$). Participants who completed the simulated job tasks during the COVID-19 pandemic had significantly faster completion times than those who completed the simulated job tasks before the COVID-19 pandemic for the hose advance and forced entry simulated job tasks ($p < 0.001$), while they had significantly slower completion times than those who completed the simulated job tasks before the COVID-19 pandemic for the rope pull and victim drag simulated job tasks ($p < 0.001$). As a result, significantly fewer individuals met the overall firefighter standard during the COVID-19 standard compared to before the COVID-19 pandemic, $p < 0.001$. This study shows that short-term reduced training, especially when customary training facilities are unavailable, has a significant negative effect on the VO_2max of firefighter applicants and significantly reduces their ability to meet the job-related aerobic fitness standard and, thus, overall job-related firefighter fitness standard.

4.2. INTRODUCTION

Firefighters must have the necessary aerobic and musculoskeletal fitness to safely and efficiently perform the most physically demanding and frequently occurring on-the-job emergency tasks in which there is a threat to life and/or property (Gumienak, Jamnik and Gledhill, 2013). Consequently, firefighter applicants generally undertake training or conditioning programs to prepare themselves to achieve the job-related aerobic and musculoskeletal fitness standards required to perform emergency on-the-job tasks safely and efficiently. Any training program should incorporate five common training principles; overload, progression, specificity, variation and reversibility (Viru, 1995). It is not uncommon for firefighters applicants to experience interruptions in their training programs due to a variety of reasons (e.g., illness, injury, pandemic, work schedules, etc.), which can lead to the partial or complete loss of training-induced performance adaptations (Fleck, 1994). This loss of performance adaptations is known as "training reversibility" and is one of the five common training principles listed above. This principle asserts that "whereas regular physical training results in several physiological adaptations, stopping or markedly reducing training results in a partial or complete reversal of these adaptations, thus compromising physical performance" (Mujika and Padilla, 2000). That is, the principle of training reversibility describes the condition of "detraining" (Hawley & Burke, 1998). However, the results of published detraining studies are equivocal. The confusion is mainly due to the diverse populations that have been studied (e.g., elite athletes, recently trained individuals, moderately active individuals, etc.) but also to the nature of the detraining (e.g., reduced training, training cessation, bed rest confinement, tapering, unloading, etc.) (Mujika and Padilla, 2000).

Most detraining studies have investigated the effects of detraining on elite athletes' physiological capacities and sports performance (Mujika and Padilla, 2000). It is important to recognize that the detraining characteristics related to moderate physical activity and improving work performance are not the same as those of highly trained athletes with a history of systematic training for several years, which has focused on improving their sports performance (Fleck, 1994). This is because the physiological adaptations gained from the regular physical training of elite athletes take longer to reverse completely than the physiological adaptations gained by moderately active and recently trained individuals. Overall, the effects of detraining on the physical and physiological attributes of moderately physically active individuals or those who train to enhance job performance are less understood than those of chronically trained athletes. When examining the impact of detraining on sports performance versus work-related performance, losses of training-induced adaptations differ depending on the duration of the interrupted training (Fleck, 1994). Based on exercise science literature, detraining periods shorter than 4 weeks are referred to as short-term detraining, and longer than 4 weeks are referred to as long-term detraining (Mujika and Padilla, 2000).

Both aerobic and musculoskeletal fitness have been documented to be critical for successful job performance in physically demanding public safety occupations (Gumienak, Jamnik and Gledhill, 2013). However, the outcomes of fitness detraining have not been assessed on work performance (i.e., the ability to carry out the most physically demanding and frequently occurring on-the-job emergency tasks). The VO_2max of moderately active and/or recently trained individuals (4 to 8 weeks of training) has been shown to decline by 3.6 to 6% during 2 to 4 weeks of training cessation (Klausen, Anderson and Pelle, 1981; Ready, Eynon and Cunningham, 1981; Pivarnik and Senay, 1986; Wibom, Hultman, Johansson, et al., 1992).

In recently trained adults (Sysler & Stull, 1970) and children (Faigenbaum et al., 1996), isokinetic strength has been reported to decline at a very fast rate but remained above pre-training values after four weeks without training. Although these studies examined some “markers” in musculoskeletal fitness, they did not examine the resultant effects of detraining on work performance, especially as it relates to work in physically demanding public safety occupations.

The emergence of COVID-19 and the numerous public lockdowns associated with this pandemic provided a unique opportunity to examine the effects of short-term detraining on the aerobic fitness and simulated job task performance of long-term moderately active or recently trained individuals. This study focuses on detraining periods lasting up to four weeks (i.e., short-term detraining) as this was the average length of time that gymnasia, fitness and recreational facilities were locked down during the various waves of the COVID-19 pandemic.

The purpose of this study was to determine what effect short-term detraining (i.e., detraining lasting < 4 weeks) has on the aerobic fitness (VO_2max) and simulated job task performance of moderately active individuals (i.e., firefighter applicants). Specifically, the first objective was to determine the effect of short-term-detraining on the VO_2max of moderately active firefighter applicants. The second objective was to determine the effect of short-term detraining on firefighter applicants' simulated job task completion times. Although musculoskeletal fitness was not measured directly, each participant's simulated job task completion times should be a good indication of their overall musculoskeletal fitness. The third objective was to determine the effects of short-term detraining on the proportion of firefighter applicants to meet the aerobic fitness standard, each simulated job task standard and the overall job-related fitness standard of the Structural Firefighter Fitness Assessment (SFFA).

It was hypothesized that short-term detraining (i.e., detraining lasting < 4 weeks) would negatively affect the VO_2max and simulated job task completion times of moderately active firefighter applicants. Consequently, a smaller proportion of individuals will meet the job-specific VO_2max standard, each simulated job task standard and the overall job-related fitness standard of the SFFA.

4.3. METHODS

4.3.1. Study participants

1718 (362 female and 1356 male) structural firefighter applicants completed a VO_2max test and the critical simulated firefighting job-related tasks between September 2016 and December 2019. During the COVID-19 pandemic between March 2020 and March 2022, 432 (71 female and 361 male) structural firefighter applicants completed a VO_2max test and several simulated firefighting job-related tasks as part of the overall SFFA protocol. Each participant provided written informed consent and agreed to have their data analyzed and reported in an anonymized group format in future research. This study was approved by the York University Human Participants Review Committee, whose research ethics guidelines are in accordance with the Canadian Tri-Council research ethics (**Certificate #: E2019-272**). Prior to the VO_2max test, each participant completed the Physical Activity Readiness Questionnaire (PAR-Q+) and, if necessary, the ePARmed-X+ (www.eparmedx.com) to ensure that they were cleared for unrestricted physical activity (i.e., moderate to maximal intensity exercise). All participants who took part in this study between March 2020 and March 2022, during the COVID-19 pandemic, were required to provide proof of COVID-19 vaccination and to complete a screening questionnaire to ensure that they had not previously tested positive for COVID-19 or that they were not currently experiencing any symptoms.

Qualified exercise professionals took pre-exercise blood pressure and heart rate measurements using the automated BpTRU blood pressure device (BpTRU Medical Devices Ltd., Coquitlam, BC, Canada). These pre-exercise measurements were used strictly to clear participants for unrestricted physical activity and were not included in the data analysis. Following the screening procedure, study participants had their sex, age, height, body mass, and body mass index (BMI) recorded. Height was measured without footwear using a wall-mounted stadiometer (Seca MPH07SH3 Mechanical Wall Mount Stadiometer, Germany) to the nearest 0.01 m, and body mass was measured while wearing light clothing and no footwear using a digital floor scale (Seca 876 Digital Floor Scale, Germany) to the nearest 0.1 kg. BMI was calculated as body mass (kg) divided by height squared (m^2).

4.3.2. Aerobic fitness test

An incremental to maximal graded exercise test (GXT) using the modified Bruce protocol plus a verification phase (VP), if required, was employed on a motorized treadmill to directly measure each participant's VO_2max. Prior to the commencement of the test, participants were given a 3-5 minute warm-up on the treadmill (3.5 mph and 2.0% incline). During that time, they were given detailed test instructions and allowed to familiarize themselves with the expired air collection apparatus. Study participants completed several progressively more demanding two-minute workloads during which cardiorespiratory measurements were collected over the final 30 seconds of each workload (the volume of expired gas, fractional concentration of oxygen (O_2) and fractional concentration of carbon dioxide (CO_2)). The first workload was performed at 5.0 mph, and the incline depended on body mass (i.e., if body mass was < 75 kg, an incline of 2.0% was used, and if their body mass was ≥ 75 kg, an incline of 4.0% was used). For each successive workload, the incline was kept constant, and the speed was increased by 1.0 mph until a comfortable running pace was achieved (between 6.0 and 7.0 mph) based on each individual's running gait and biomechanics. Once their maximal speed was attained, the incline was increased by 2.0% every workload and speed was kept constant until VO_2max was attained or they could not continue (i.e., volitional fatigue).

VO_2max values were considered valid only if a VO_2 plateau was attained (i.e., an increase in $VO_2 < 150\ mL\cdot min^{-1}$ or $< 2.5\ mL\cdot kg^{-1}\cdot min^{-1}$ between consecutive workloads despite an increase in intensity). If valid VO_2max values were attained, the individuals were instructed to perform a 3-5 minute cool-down (3.5 mph and 2.0% incline). However, if participants did not reach a valid VO_2max during the incremental to maximal GXT, they were instructed to perform one or more discontinuous supramaximal verification workload(s) during the VP. These verification workloads, separated by two-minute active-rest periods (3.5 mph and 2.0% incline), were performed at the same speed as the incremental to maximal GXT but at progressively higher inclines (2.0% greater than that used during the last stage of the GXT). These verification workloads were performed until a valid VO_2max was attained. At that time, the participants were instructed to perform a 3-5 minute cool-down at 3.5 mph and 2.0% incline.

4.3.3. Simulated job tasks

Participants were given a 10-minute rest after the aerobic fitness test before attempting the simulated job tasks. The hose carry, rope pull, hose advance, victim drag, and forced entry simulated job tasks were each completed individually, and participants were required to meet SFFA completion time standards. The ladder lift simulated job task was not timed and was scored on a pass-or-fail basis. Individuals who were unable to complete a simulated job task successfully or whose completion time was too slow were given one re-test opportunity of that job task during the testing session. The performance scores for each simulated job task (i.e., meets standard or does not meet standard) were based on individuals completing the simulated job tasks at a safe and expeditious pace (i.e., no running was allowed). Participants were required to meet the SFFA completion time standards for all individual simulated job tasks to meet the overall simulated job performance standard.

4.3.3.1. Hose carry. Participants were instructed to lift a bundle of tied hose (85 lb; 38.5 kg) from the floor level up and onto their preferred shoulder. They were then required to carry the bundle up and down a set of stairs two times for a total height of 100 ft (30.5 m). Timing began when the participants bent to pick up the bundle of hose and ended when they reached the bottom of the stairs for the second time. Throughout this task, the individuals were required to wear a 32 lb (14.5 kg) weighted vest and 8 lb (3.6 kg) ankle weights to simulate the weight of PPE.

4.3.3.2. Rope pull. Using a rope, participants were required to hoist and lower the weight of a 50 ft (15.2 m) section of hose plus nozzle (50 lb; 22.7 kg) up and down a total height of 65 ft (19.8 m) two times. This was to be done in a hand-over-hand controlled motion, both up and down. During the task, the participants were not allowed to rest their arms on the railing or hoist the weight by moving their feet backwards. Timing began when the participants began to hoist the weight and ended when they finished lowering it for the second time. Throughout this task, the individuals were required to wear the simulated PPE.

4.3.3.3. Hose advance. Via a strap held over their shoulder, participants were required to apply a force of 135 lb or 600.5 Newtons (N) to reposition two sections of charged hose a distance of 50 ft (15.2 m). Timing started when the front of the sled crossed the start line and finished when the rear of the sled crossed the finish line. During the task, participants were required to look straight ahead and not touch any walls or supports. Throughout this task, the individuals were required to wear the simulated PPE.

4.3.3.4. Ladder lift. Participants were required to remove and replace a standard ladder (56.2 lb; 25.5 kg) ladder from brackets mounted 1.93 m (6.3 ft) above the floor (the height of the brackets on standard fire trucks). This task was not timed and was scored on a pass-or-fail basis. Throughout this task, the individuals were required to wear the simulated PPE.

4.3.3.5. Victim drag. Participants were required to drag a 200 lb (90.7 kg) dummy by a handle behind its' neck a distance of 25 ft (7.6 m) from the starting line and 25 ft (7.6 m) back to the starting line, weaving in and out of traffic cones placed every 8 ft (2.4 m). Timing began when the participants bent to lift the dummy and ended when they re-crossed the starting line and turned the dummy around, so it was ready for the next participant. Throughout this task, the individuals were required to wear the simulated PPE.

4.3.3.6. Forced entry. Participants were required to move a heavily weighted tire a total of 12 inches (0.3 m) by hitting the tire repeatedly with a 10 lb (4.5 kg) sledgehammer until the tire moved far enough to contact a 12-inch (0.3 m) marker. The height of the table was the height of a door handle at which a sledgehammer or axe is normally swung while conducting a forced entry. Timing began when the participants took their first backswing and ended when the tire reached the marker. Throughout this task, the individuals were required to wear the simulated PPE.

4.3.4. Statistical analysis

Analyses were performed using IBM SPSS Statistics for Macintosh, version 27.0 (IBM Corp., Armonk, N.Y., USA) and a significance threshold of $p < 0.05$ was considered statistically significant. Descriptive characteristics (i.e., age, height, body mass and BMI), relative VO_2max and simulated job task completion times are presented in Tables 27, 28 and 29 as means $\pm$ standard deviation. Sex and simulated job task performance scores (i.e., meets the standard or does not meet the standard) are presented as frequencies, n (%). Independent-samples t-tests were run to determine if there were any significant differences in descriptive characteristics between pre- and post-COVID-19 pandemic study participants. Independent-samples t-tests were run to determine significant differences in VO_2max values between pre- and post-COVID-19 pandemic study participants. Chi-square tests for homogeneity were used to determine if differences existed between the number of study participants to meet the VO_2max test standard pre- and post-COVID-19 pandemic. Independent-samples t-tests were run to determine significant differences between simulated job task completion times pre- and post-COVID-19 pandemic. Chi-square tests for homogeneity were run to determine if there were significant differences between the proportion of participants to meet the standards pre- and post-COVID-19 pandemic. Chi-square tests for homogeneity were run to determine if there were significant differences between the proportion of participants to meet the SFFA standards pre- and post-COVID-19 pandemic.

4.4. RESULTS

4.4.1. Descriptive characteristics

Table 29 presents the descriptive characteristics of the structural firefighter applicants who participated in this study before and during the COVID-19 pandemic. Results are presented as combined as well as stratified by sex. There were 2150 participants; 1718 applicants participated in this study before the COVID-19 pandemic (September 2016 to December 2019), while 432 applicants participated in this study during the COVID-19 pandemic (March 2020 to March 2022). Independent-samples t-tests were run to determine significant differences in descriptive characteristics between the two groups. The male firefighter applicants who took part in this study during the COVID-19 pandemic were significantly older than the male firefighter applicants who took part in this study before the COVID-19 pandemic, 30.0 $\pm$ 6.6 years versus 28.4 $\pm$ 6.3 years, a statistically significant difference of 1.6 years (95% CI, 0.849 to 2.320), $t(1715) = -4.227$, $p < 0.001$. Also, when the female and male participants' data were combined, firefighter applicants who took part in this study during the COVID-19 pandemic were significantly older than those who took part in this study before the COVID-19 pandemic, 29.8 ± 6.6 years versus 28.3 ± 6.3 years, a statistically significant difference of 1.5 years (95% CI, 0.745 to 2.089), $t(2148) = -4.136$, $p < 0.001$. There were no significant differences in height, body mass or BMI between the firefighter applicants who took part in the study during the COVID-19 pandemic and those who took part in the study before the COVID-19 pandemic, $p > 0.05$.

Table 29. Descriptive characteristics of study III participants collected before and during the COVID-19 pandemic.

	Before COVID-19			During COVID-19		
	Females	Males	Combined	Females	Males	Combined
Sample size, n (%)	362 (21.1)	1356 (78.9)	1718 (100)	71 (16.4)	361 (83.6)	432 (100)
Age, yr.	28.1 ± 6.5	28.4 ± 6.3	28.3 ± 6.3	28.6 ± 6.6	**30.0 ± 6.6****	**29.8 ± 6.6****
Height, m	1.69 ± 0.06	1.80 ± 0.07	1.76 ± 0.08	1.69 ± 0.06	1.80 ± 0.07	1.78 ± 0.08
Body mass, kg	71.2 ± 10.0	86.8 ± 12.7	83.5 ± 13.7	73.4 ± 12.1	86.8 ± 13.1	84.6 ± 13.8
BMI, kg/m^2	25.1 ± 3.2	26.7 ± 3.4	26.4 ± 3.4	25.8 ± 3.8	26.7 ± 3.5	26.5 ± 3.6

Values are presented as mean ± standard deviation (SD) unless otherwise stated.
Note: Independent-samples t-tests were run to determine significant differences in descriptive characteristics between the before and during COVID-19 pandemic study participants.
**$p < 0.001$.

4.4.2. Aerobic fitness test results

Table 30 presents the VO_2max values and the number (proportion) of study participants to meet the VO_2max test standards before and during the COVID-19 pandemic. Results are presented as combined as well as stratified by sex. Female firefighter applicants who took part in this study during the COVID-19 pandemic had significantly lower VO_2max values (40.5 ± 5.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) than female firefighter applicants who took part in this study before the COVID-

19 pandemic (44.0 ± 5.6 mL·kg^{-1}·min^{-1}), a significant difference of 3.5 mL·kg^{-1}·min^{-1} (95% CI, 2.06 to 4.85), $t(431) = 4.876$, $p < 0.001$. Consequently, a significantly smaller proportion of female participants were able to meet the VO_2max standard during the COVID-19 pandemic (26.8%) compared to before the COVID-19 pandemic (48.1%), a difference in proportions of 0.213, $p < 0.05$. Male firefighter applicants who took part in this study during the COVID-19 pandemic (47.8 ± 5.9 mL·kg^{-1}·min^{-1}) had significantly lower VO_2max values than male firefighter applicants who took part in this study before the COVID-19 pandemic (50.1 ± 6.6 mL·kg^{-1}·min^{-1}), a significant difference of 2.3 mL·kg^{-1}·min^{-1} (95% CI, 1.54 to 3.04), $t(1715) = 5.982$, $p < 0.001$. Consequently, a significantly smaller proportion of male participants were able to meet the VO_2max standard during the COVID-19 pandemic (69.0%) compared to before the COVID-19 pandemic (80.2%), a difference in proportions of 0.112, $p < 0.001$. When the female and male participants were combined, firefighter applicants who took part in this study during the COVID-19 pandemic (46.6 ± 6.4 mL·kg^{-1}·min^{-1}) had significantly lower VO_2max values than firefighter applicants who took part in this study before the COVID-19 pandemic (48.8 ± 6.9 mL·kg^{-1}·min^{-1}), a significant difference of 2.2 mL·kg^{-1}·min^{-1} (95% CI, 1.48 to 2.91), $t(2148) = 6.020$, $p < 0.001$. Consequently, a significantly smaller proportion of firefighter applicants were able to meet the VO_2max test standard during the COVID-19 pandemic (62.0%) compared to before the COVID-19 pandemic (73.5%), a difference in proportions of 0.115, $p < 0.001$.

Table 30. The VO_2max values and number (proportion) of study III participants to meet the aerobic fitness test standards before and during the COVID-19 pandemic.

	Before COVID-19			During COVID-19		
	Females	Males	Combined	Females	Males	Combined
Sample size, n (%)	362 (21.1)	1356 (78.9)	1718 (100)	71 (16.4)	361 (83.6)	432 (100)
VO_2max, $mL \cdot kg^{-1} \cdot min^{-1}$	44.0 ± 5.6	50.1 ± 6.6	48.8 ± 6.9	**40.5 ± 5.0****	**47.8 ± 5.9****	**46.6 ± 6.4****
Meets standard, n (%)	174 (48.1)	1088 (80.2)	1262 (73.5)	**19 (26.8)***	**249 (69.0)****	**268 (62.0)****

Values are presented as mean ± standard deviation (SD) unless otherwise stated.
Note: Independent-samples t-tests were run to determine significant differences in VO_2max values between the before and during COVID-19 pandemic study participants. Chi-square tests for homogeneity were used to determine if differences existed between the number of study participants to meet the aerobic fitness test standards before and during the COVID-19 pandemic.
*$p < 0.05$. **$p < 0.001$.

4.4.3. Simulated job task completion times

Table 31 presents the number and proportion of participants to complete each simulated job task and their related mean completion times both before and during the COVID-19 pandemic. The completion times reported in Table 31 are derived from the completion times of participants who could successfully complete each simulated job task. Independent-samples t-tests were run to determine significant differences between simulated job task completion times before and during the COVID-19 pandemic. There were no outliers in the data, as assessed by inspection of the boxplots, and simulated job task completion times were normally distributed, as assessed by Shapiro-Wilk's test ($p < 0.05$). Where any assumptions of homogeneity of variances were violated, as assessed by Levene's test for equality of variances ($p < 0.05$), Welch t-tests were run to determine if there were significant differences between the before and during COVID-19 pandemic completion times.

Table 31. The number and proportion of study III participants to complete each simulated job task and the related completion times collected before and during the COVID-19 pandemic.

	Before COVID-19			During COVID-19		
	Females	Males	Combined	Females	Males	Combined
Hose carry						
Completed, n(%)	275 (76.0)	1323(97.6)	1598(93.0)	59(83.1)	358(99.2)	417(96.5)
Time, s	142.7 ± 14.7	127.2 ± 14.6	129.8 ± 15.7	147.8 ± 21.9	125.4 ± 17.0	128.5 ± 19.4
Rope pull						
Completed, n (%)	279(77.1)	1330(98.1)	1609(93.7)	53(76.3)	360(99.7)	413(95.6)
Time, s	63.4 ± 11.1	45.6 ± 9.2	48.7 ± 11.7	**68.7 ± 14.6***	**48.7 ± 10.5****	**51.3 ± 13.0****
Hose advance						
Completed, n (%)	256(70.7)	1283(94.6)	1539(89.6)	53(76.3)	357(98.9)	410(94.9)
Time, s	28.8 ± 8.6	17.4 ± 6.4	19.3 ± 8.0	**24.1 ± 10.1****	**14.9 ± 6.5****	**16.1 ± 7.7****
Ladder lift						
Completed, n (%)	313(86.5)	1339(98.7)	1652(96.2)	54(91.5)	331(99.7)	385(98.5)
Time, s	n/a	n/a	n/a	n/a	n/a	n/a
Victim drag						
Completed, n (%)	321(88.7)	1325(97.7)	1646(95.8)	59(83.1)	360(99.7)	419(97.0)
Time, s	22.5 ± 3.0	19.3 ± 3.0	20.0 ± 3.2	**24.5 ± 2.7****	**20.4 ± 3.2****	**20.9 ± 3.4****
Forced entry						
Completed, n (%)	273(75.4)	1306(96.3)	1579(91.9)	46(64.8)	352(97.5)	398(92.1)
Time, s	15.6 ± 4.2	9.5 ± 3.3	10.5 ± 4.2	16.4 ± 5.1	**8.8 ± 3.1****	**9.7 ± 4.2****

Values are presented as mean ± standard deviation (SD) unless otherwise stated.
Note: Independent-samples t-tests were run to determine significant differences between simulated job task completion times before and during the COVID-19 pandemic.
*$p < 0.05$. **$p < 0.001$.

4.4.3.1. Hose carry. For the hose carry, there were no significant differences between the completion times recorded during the COVID-19 pandemic and those recorded before the COVID-19 pandemic, $p > 0.05$. This is true for female and male firefighter applicants, $p > 0.05$.

4.4.3.2. Rope pull. Female participants who completed the rope pull during the COVID-19 pandemic (68.7 ± 14.6 seconds) had significantly slower completion times than female participants who completed the rope pull before the COVID-19 pandemic (63.4 ± 11.1 seconds), a statistically significant difference of 5.3 seconds (95% CI, 1.82 to 8.73), $t(330) = -3.003$, $p = .003$. Male participants who completed the rope pull during the COVID-19 pandemic (48.7 ± 10.5 seconds) had significantly slower completion times than male participants who completed the rope pull before the COVID-19 pandemic (48.7 ± 10.5 seconds), a statistically significant difference of 3.2 seconds (95% CI, 2.02 to 4.24), $t(518.112) = -5.144$, $p < .001$. When combined, participants who completed the rope pull during the COVID-19 pandemic (51.3 ± 13.0 seconds) had significantly slower completion times than participants who completed the rope pull before the COVID-19 pandemic (48.7 ± 11.7 seconds), a statistically significant difference of 2.6 seconds (95% CI, 1.31 to 3.90), $t(2020) = -3.939$, $p < .001$.

4.4.3.3. Hose advance. Female participants who completed the hose advance during the COVID-19 pandemic (24.1 ± 10.1 seconds) had significantly faster completion times than female participants who completed the hose advance before the COVID-19 pandemic (28.8 ± 8.6 seconds), a statistically significant difference of 4.7 seconds (95% CI, 2.02 to 7.30), $t(307) = 3.478$, $p < .001$. Male participants who completed the hose advance during the COVID-19 pandemic (14.9 ± 6.5 seconds) had significantly faster completion times than male participants who completed the hose advance before the COVID-19 pandemic (17.4 ± 6.4 seconds), a statistically significant difference of 2.4 seconds (95% CI, 1.67 to 3.19), $t(563.446) = 6.267$, $p < .001$. When combined, participants who completed the hose advance during the COVID-19 pandemic (16.1 ± 7.7 seconds) had significantly faster completion times than participants who completed the hose advance before the COVID-19 pandemic (19.3 $\pm$ 8.0 seconds), a statistically significant difference of 3.1 seconds (95% CI, 2.27 to 4.01), $t(1975) = 3.741$, $p < .001$.

4.4.3.4. Ladder lift. Independent-samples t-tests could not be run for the ladder lift because this task was scored on a pass/fail basis and was not timed. Only the number and proportion of participants to complete the ladder lift were recorded. However, the proportion of participants who successfully completed the ladder lift during the COVID-19 pandemic was not statistically different from that of participants who successfully completed the ladder lift before the COVID-19 pandemic, $P > 0.05$ (Table 30).

4.4.3.5. Victim drag. Female participants who completed the victim drag during the COVID-19 pandemic (24.5 $\pm$ 2.7 seconds) had significantly slower completion times than female participants who completed the victim drag before the COVID-19 pandemic (22.5 $\pm$ 3.0 seconds), a statistically significant difference of 2.0 seconds (95% CI, 1.15 to 2.78), $t(378) = -4.750$, $p < .001$. Male participants who completed the victim drag during the COVID-19 pandemic (20.4 $\pm$ 3.2 seconds) had significantly slower completion times than male participants who completed the victim drag before the COVID-19 pandemic (19.3 $\pm$ 3.0 seconds), a statistically significant difference of 1.0 seconds (95% CI, 0.67 to 1.38), $t(1683) = -5.665$, $p < .001$. When combined, participants who completed the victim drag during the COVID-19 pandemic (20.9 $\pm$ 3.4 seconds) had significantly slower completion times than participants who completed the victim drag before the COVID-19 pandemic (20.0 $\pm$ 3.2 seconds), a statistically significant difference of 1.0 seconds (95% CI, 0.67 to 1.38), $t(1683) = -5.665$, $p < .001$.

4.4.3.6. Forced entry. Female participants who completed the forced entry during the COVID-19 pandemic did not have significantly different completion times than female participants who completed the forced entry before the COVID-19 pandemic, p = .307. Male participants who completed the forced entry during the COVID-19 pandemic (8.8 $\pm$ 3.1 seconds) had significantly faster completion times than male participants who completed the forced entry before the COVID-19 pandemic (9.5 $\pm$ 3.3 seconds), a statistically significant difference of 0.7 seconds (95% CI, 0.67 to 1.38), t(1683) = -5.665, p < .001. When combined, participants who completed the forced entry during the COVID-19 pandemic (9.7 $\pm$ 4.2 seconds) had significantly faster completion times than participants who completed the forced entry before the COVID-19 pandemic (10.5 $\pm$ 4.2 seconds), a statistically significant difference of 0.9 seconds (95% CI, 0.42 to 1.33), t(1975) = 3,741, p < .001.

4.4.4. Simulated job task performance scores

Tests of two proportions were used to compare the proportions of participants who met the completion time standards for each simulated job task before and during the COVID-19 pandemic (Table 32). The tests of two proportions used were the chi-square tests for homogeneity.

Table 32. The number and proportion of study III participants to successfully meet each simulated job task standard and the overall simulated job task standard before and during the COVID-19 pandemic.

	Before COVID-19			During COVID-19		
	Females	Males	Combined	Females	Males	Combined
Hose carry						
Meets standard, n(%)	273 (75.4)	1323 (97.6)	1596 (92.9)	57 (80.3)	358 (99.2)	**415 (96.1)***
Rope pull						
Meets standard, n (%)	279 (77.1)	1330 (98.1)	1609 (93.7)	51 (71.8)	**360 (99.7)***	411 (95.1)
Hose advance						
Meets standard, n (%)	255 (70.4)	1283 (94.6)	1538 (89.5)	52 (73.2)	**356 (98.6)***	**408 (94.4)***
Ladder lift						
Meets standard, n (%)	313 (86.5)	1339 (98.7)	1652 (96.2)	61 (85.9)	359 (99.4)	420 (97.7)
Victim drag						
Meets standard, n (%)	321 (88.7)	1325 (97.7)	1646 (95.8)	59 (83.1)	**360 (99.7)***	419 (97.0)
Forced entry						
Meets standard, n (%)	273 (75.4)	1305 (96.2)	1578 (91.9)	**45 (63.4)***	352 (97.5)	397 (91.9)
Overall job-related fitness test						
Meets standard, n (%)	189 (52.2)	1238 (91.3)	1427 (83.1)	39 (54.9)	**347 (96.1)***	**386 (89.4)***

Note: Chi-Square tests for homogeneity were run to determine if there were significant differences between the proportion of participants to meet the standards before and during the COVID-19 pandemic.
*p < 0.05. **p < 0.001.

4.4.4.1. Hose carry. For the hose carry, 415 (96.1%) study participants were able to meet the completion time standard during the COVID-19 pandemic and 1596 (92.9%) study participants were able to meet the performance time standard before the COVID-19 pandemic, a significant increase in the proportion of 0.032, $p < 0.05$ (Table 30). When the study participants were stratified by sex, there were no significant differences between the proportion of individuals to meet the completion time standard during COVID-19 and before COVID-19, $p > 0.05$. (Table 32).

4.4.4.2. Rope pull. For the rope pull, 360 (99.7%) male participants were able to meet the completion time standard during the COVID-19 pandemic and 1330 (98.1%) male participants were able to meet the performance time standard before the COVID-19 pandemic, a significant increase in the proportion of 0.016, $p < 0.05$ (Table 30). The proportions of combined and female participants to meet the rope pull performance time standard during the COVID-19 pandemic were not significantly different from those of combined and female participants to meet the rope pull performance time standard before the COVID-19 pandemic, $p > 0.05$ (Table 32).

4.4.4.3. Hose advance. For the hose advance, 408 (94.4%) study participants were able to meet the completion time standard during the COVID-19 pandemic and 1538 (89.5) study participants were able to meet the performance standard before the COVID-19 pandemic, a significant increase in the proportion of .099, $p < 0.05$ (Table 30). When stratified by sex, 356 (98.6%) male participants were able to meet the hose advance performance standard during the COVID-19 pandemic and 1538 (89.5%) male participants were able to meet the performance standard before the COVID-19 pandemic, a significant increase in the proportion of 0.04, $p < 0.05$ (Table 30). The proportion of female participants to meet the hose advance performance time standard during the COVID-19 pandemic was not significantly different from that of female participants to meet the hose advance performance time standard before the COVID-19 pandemic, $p > 0.05$ (Table 32).

4.4.4.4. Ladder lift. For the ladder lift, there were no significant differences between the proportion of participants to meet the performance standard during the COVID-19 pandemic and the proportion of participants to meet the performance standard before the COVID-19 pandemic, $p > 0.05$ (Table 32).

4.4.4.5. Victim drag. For the victim drag, 360 (99.7%) male participants were able to meet the completion time standard during the COVID-19 pandemic and 1325 (97.7%) male participants were able to meet the performance time standard before the COVID-19 pandemic, a significant increase in the proportion of 0.020, $p < 0.05$ (Table 30). The proportions of combined and female participants to meet the victim drag performance time standard during the COVID-19 pandemic were not significantly different from the proportions of combined and female participants to meet the victim drag performance time standard before the COVID-19 pandemic, $p > 0.05$ (Table 32).

4.4.4.6. Forced entry. For the forced entry, 45 (63.4%) female participants were able to meet the completion time standard during the COVID-19 pandemic and 273 (75.4%) female participants were able to meet the performance time standard before the COVID-19 pandemic, a significant decrease in the proportion of 0.120, $p < 0.05$ (Table 32).

4.4.4.7. Overall simulated job tasks. When males and females were combined, 386 (89.4%) study participants were able to meet the overall simulated job task performance standard during the COVID-19 pandemic and 1427 (83.1%) study participants were able to meet the performance standard before the COVID-19 pandemic, a significant increase in the proportion of 0.063, $p < 0.05$ (Table 32). In addition, 347 (96.1%) male participants were able to meet the performance standard during the COVID-19 pandemic and 1238 (91.3%) male participants were able to meet the performance standard before the COVID-19 pandemic, a significant increase in the proportion of 0.048, $p < 0.05$ (Table 32). The proportion of female participants to meet the overall performance standard during the COVID-19 pandemic was not significantly different from that of female participants to meet the overall performance standard before the COVID-19 pandemic, $p > 0.05$ (Table 32).

4.4.5. Overall Structural Firefighter Fitness Assessment scores

To meet the overall SFFA standard, study participants must meet both the aerobic fitness and simulated job task standards. Tests of two proportions were used to compare the proportions of participants who met the overall SFFA standards during and before the COVID-19 pandemic. The tests of two proportions used were the chi-square tests for homogeneity. 252 (58.3%) study participants were able to meet the overall SFFA standards during the COVID-19 pandemic and 1121 (65.3%) study participants were able to meet the overall SFFA standards before the COVID-19 pandemic, a significant decrease in the proportion of 0.070, $p < 0.05$ (Table 33). 238 (65.9%) male participants were able to meet the overall SFFA standards during the COVID-19 pandemic, and 1007 (74.3%) male participants were able to meet the overall SFFA standards before the COVID-19 pandemic, a significant decrease in the proportion of 0.084, $p < 0.05$ (Table 33). Finally, 14 (19.7%) female participants were able to meet the overall SFFA standards during the COVID-19 pandemic, and 114 (31.5%) female participants were able to meet the overall SFFA standards before the COVID-19 pandemic, a significant decrease in the proportion of 0.118, $p < 0.05$ (Table 33).

Table 33. The number and proportion of study III participants to successfully meet the overall Structural Firefighter Fitness Assessment (SFFA) standards before and during the COVID-19 pandemic.

	Before COVID-19			During COVID-19		
	Females	Males	Combined	Females	Males	Combined
Meets SFFA standard, n (%)	114 (31.5)	1007 (74.3)	1121 (65.3)	**14 (19.7)***	**238 (65.9)***	**252 (58.3)***

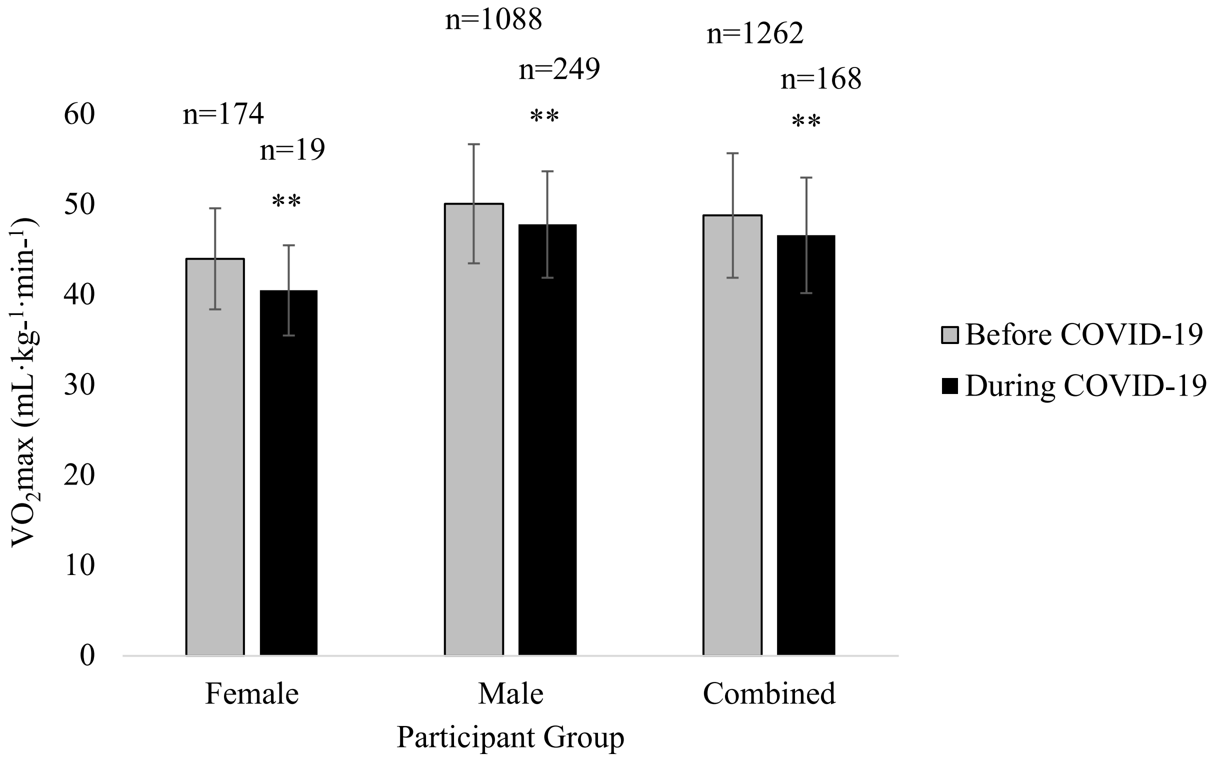
Note: Chi-Square tests for homogeneity were run to determine if there were significant differences between the proportion of participants to meet the standards before and during the COVID-19 pandemic.
*$p < 0.05$.

4.5. DISCUSSION

Short-term detraining significantly decreased the aerobic fitness levels of structural firefighter applicants. The VO_2max values of female, male and combined participants who took part in the study during the COVID-19 pandemic were 8.0%, 4.6% and 4.5% less than those who took part in the study before the COVID-19 pandemic, respectively (Figure 6). These findings are similar to those reported in previous short-term detraining studies where the VO_2max of moderately active and recently trained individuals (4 to 8 weeks of training) was shown to decline by 3.6% to 6% during 2 to 4 weeks of training cessation (Klausen, Anderson and Pelle, 1981; Ready, Eynon and Cunningham, 1981; Pivarnik and Senay, 1986; Wibom, Hultman, Johansson, et al., 1992). Interestingly, another study found an 11.7% reduction in the VO_2max values of elite female soccer players after a 41-day significant reduction in training activity due to the COVID-19 lockdown (Berkowicz and Obminski, 2021). Although the female soccer players in this study were considered "elite", their mean VO_2max prior to detraining was only 47.9 ± 4.0 $mL \cdot kg^{-1} \cdot min^{-1}$. This was only slightly higher than that of the female participants in our study before the COVID-19 pandemic (44.0 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$) and during the COVID-19 pandemic (40.5 ± 5.0 $mL \cdot kg^{-1} \cdot min^{-1}$). It was also lower than that of our male participants before the COVID-19 pandemic (50.1

$\pm$ 6.6 $mL \cdot kg^{-1} \cdot min^{-1}$) and the same as our male participants during the COVID-19 pandemic (47.8 $\pm$ 5.9 $mL \cdot kg^{-1} \cdot min^{-1}$). Additionally, their study used the *beep test* to measure aerobic fitness and did not use the "gold standard" VO_2max test using indirect calorimetry. This could have affected the accuracy of their VO_2max measurements both before and after detraining for 41 days. Similar to our study, there was no controlled training or physical activity monitoring of the study participants during the lockdown. These results support the findings of Shepard (1994), who found that cessation of exercise training causes a significant reduction in VO_2max and decreases overall plasma volume within only two weeks. Additionally, they found that all prior functional gains are reduced within 2 to 8 months of training cessation, even if routine low- to moderate-intensity physical activity has been continued (Shephard, 1994). The VO_2max loss during training cessation seems to depend on the duration of detraining and initial fitness level (Mujika and Padilla, 2000).

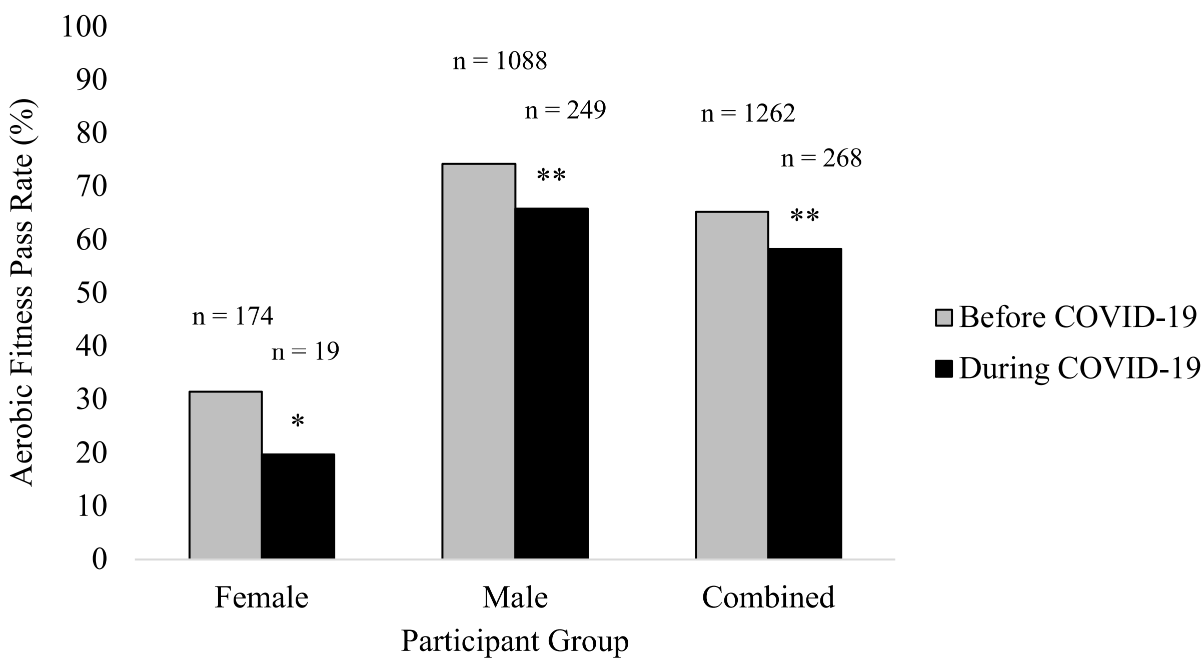
Figure 6. The VO_2max of study III participants measured before and during the COVID-19 pandemic.



** Denotes significance from before COVID-19 to during COVID-19, $p < 0.001$.

The outbreak of the COVID-19 pandemic, and the numerous short-term lockdowns associated with it, restricted people's access to commercial gyms and fitness facilities, thus reducing their ability to perform regular aerobic exercise. These short-term "breaks" from regular aerobic exercise are thought to be the main reason for the significant decreases in aerobic fitness. Consequently, significantly fewer individuals could meet the aerobic fitness standard during the COVID-19 pandemic compared to before the COVID-19 pandemic. Female, male and joint participants who completed the aerobic fitness test during the COVID-19 pandemic, were 21.3%, 11.2% and 11.5% less likely to meet the aerobic fitness standard than those who completed the aerobic fitness test before the COVID-19 pandemic (Figure 7). These significant decreases in the proportion of individuals to meet the aerobic fitness standard can be attributed to I) the fact that the participants were recently trained or moderately active and had VO_2max values that were, on average, slightly greater than the aerobic fitness standard (42.5 $mL \cdot kg^{-1} \cdot min^{-1}$) and ii) the significantly lower VO_2max scores measured during the COVID-19 pandemic compared to before the COVID-19 pandemic. In other words, even small changes in the VO_2max values of these participants could change their ability to meet the aerobic fitness standard.

Figure 7. The percentage of study participants to meet the aerobic fitness standard for structural firefighters before and during the COVID-19 pandemic.



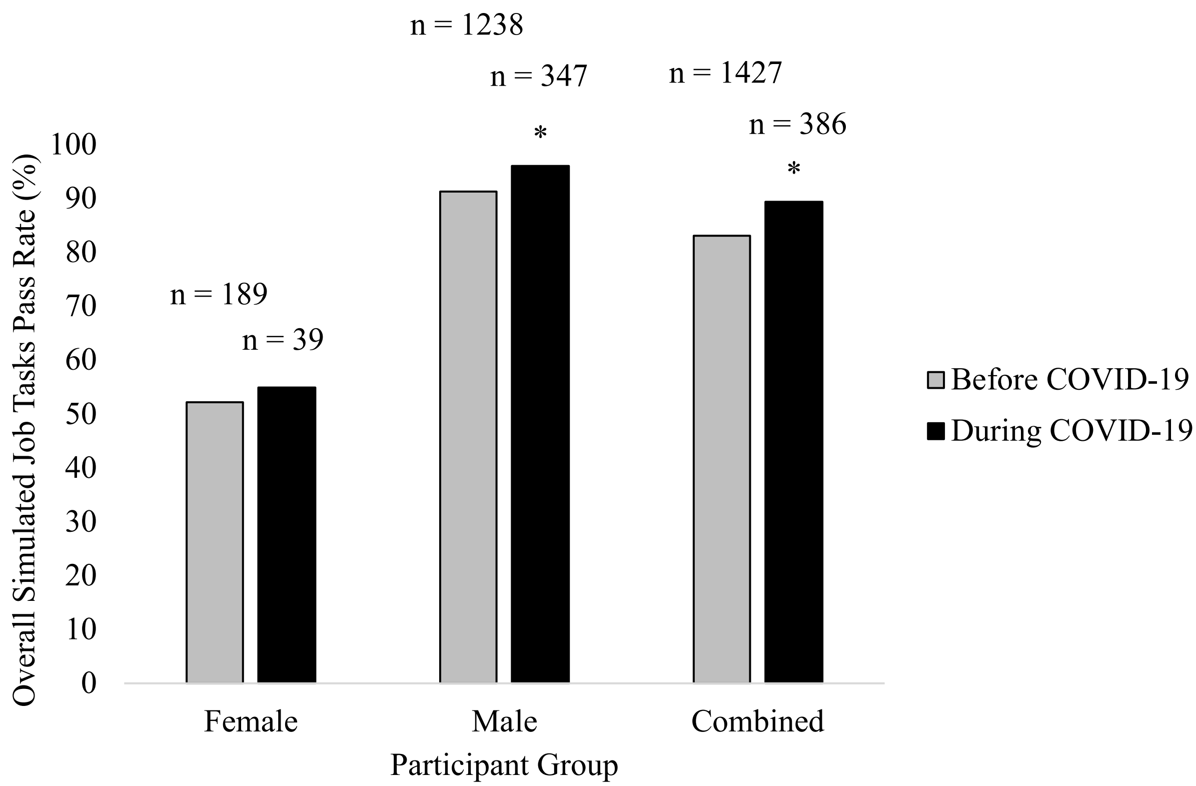
*Denotes significance from before COVID-19 to during COVID-19, $p < 0.05$
** Denotes significance from before COVID-19 to during COVID-19, $p < 0.001$.

Interestingly, similar significant results were not found for the simulated job tasks portion of the SFFA. In fact, the mean completion times during the COVID-19 pandemic for female, male and combined participants were I) the same than before the COVID-19 pandemic for some simulated job tasks (e.g., the hose carry), ii) significantly faster than before the COVID-19 pandemic for some simulated job tasks (e.g., the hose advance and forced entry), and iii) significantly slower than before the COVID-19 pandemic for some simulated job tasks (e.g., the rope pull and victim drag). These results were not expected as it was hypothesized that the study participants would have significantly slower simulated job task completion times during the COVID-19 pandemic than before the COVID-19 pandemic. However, many studies have shown that muscular strength and power, similar to that needed to complete each simulated job task, are reduced at a much slower rate than VO_2max, particularly during the first few months after an individual discontinues resistance training (Fleck & Kraemer, 1987). In fact, no significant loss in either strength or power may occur for the first 4 to 6 weeks after training ends (Neufer et al., 1987), and almost half of the strength gained by an individual might still be kept after 12 months if they still are moderately active (Wilmore & Costill, 1994).

Consequently, based on I) the short-term duration of resistance training reduction (< 4 weeks) and ii) the fact that successful simulated job task completion times require musculoskeletal strength, power and endurance, it is not surprising that the simulated job task completion times collected during the COVID-19 pandemic were not significantly slower than the simulated job task completion times collected before the COVID-19 pandemic. In addition, one thing that might have affected these results is that the mean completion times (both before and during the COVID-19 pandemic) were derived only from the individual completion times of study participants who were able to complete each simulated job task. In other words, if a study participant could not complete a simulated job task, their completion time was not included in the data analysis. Furthermore, depending on how long it was taking them to complete any given simulated job task, study participants would have been recommended to stop the attempt if the completion time standard had already passed (i.e., if the study participant was not close to completing a simulated job task and the completion time standard had already passed, the study participant would have been recommended to stop their attempt).

The proportion of participants to successfully meet each simulated job task standard and the overall simulated job task standard during the COVID-19 pandemic were not all significantly different than the proportion of participants to successfully meet each simulated job task standard and the overall simulated job task standard during the COVID-19 pandemic (Figure 8). In fact, for both the overall simulated job task score and many individual simulated job task scores, a larger proportion of individuals were able to meet the completion time standards during the COVID-19 pandemic compared to before the COVID-19 pandemic. This is because the proportion of individuals to meet these standards is dependent on their ability to successfully complete each simulated job task at a safe and effective pace.

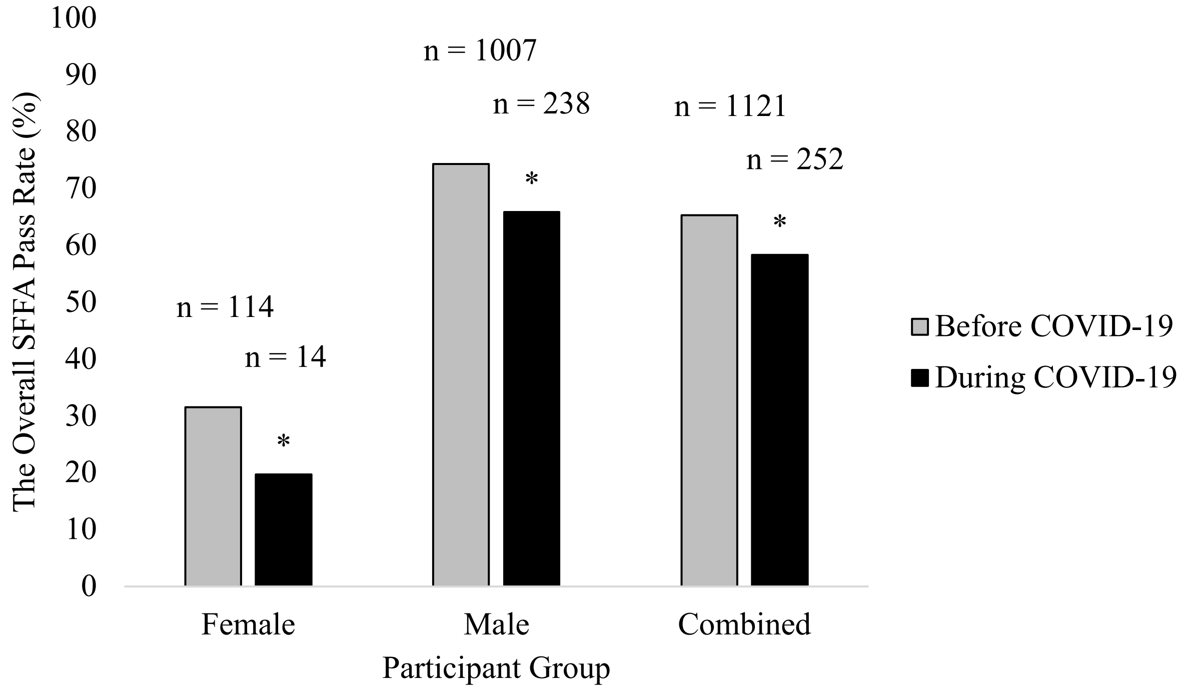
Figure 8. The percentage of study III participants to meet the overall simulated job tasks standard for structural firefighters before and during the COVID-19 pandemic.



*Denotes significance from before COVID-19 to during COVID-19, $p < 0.05$

The proportion of participants who successfully met the overall SFFA standard during the COVID-19 pandemic was significantly less than that of participants who successfully met the overall SFFA standard before the COVID-19 pandemic. This is true for female, male and combined study participants (Figure 9). Because an individual's ability to meet the overall SFFA standard is dependent on I) their ability to meet the aerobic fitness standard and II) their ability to meet the overall simulated job task standard, it becomes very clear that the significant reduction in the proportion of individuals to meet the overall SFFA standard is driven primarily by the significantly reduced VO_2max values and aerobic fitness test scores.

Figure 9. The percentage of study III participants to meet the overall Structural Firefighter Fitness Assessment (SFFA) standard before and during the COVID-19 pandemic.



*Denotes significance from before COVID-19 to during COVID-19, $p < 0.05$.

4.6. CONCLUSION

Industrial athletes in physically-demanding public safety occupations must pass physical and physiological fitness tests before being hired as front-line workers to ensure that they can perform the most physically demanding and often occurring on-the-job tasks safely and efficiently. However, in many of these occupations, industrial athletes do not need to complete annual fitness testing once hired. This study shows that short-term detraining has a significant and negative effect on the aerobic fitness (VO_2max) of moderately-active firefighter applicants and significantly reduces their ability to meet the job-specific aerobic fitness standard and, therefore, overall SFFA standard. These results supply support for annual and return-to-work fitness testing for industrial athletes.

CHAPTER 5: LIMITATIONS and IMPLICATIONS OF FINDINGS

5.1. LIMITATIONS

This research project is subject to a few limitations. First, all the study participants included in the three research studies were individuals applying to front-line positions in physically demanding public safety occupations. More specifically, they were all applicants undergoing the Structural Firefighter Fitness Assessment (SFFA) as part of a hiring process. Therefore, the individuals who participated in this research project were part of a very unique and particular population. As the research aims of this project were meant specifically for this population, this does not present a very large limitation. However, any conclusions made from these research studies might not be applicable or relevant to other populations (e.g., elite athletes, general populations, etc.) who do not possess the same aerobic and musculoskeletal fitness levels. Future research should attempt to answer similar research questions with various populations to ensure that the results are universal. Second, because this research project deals with such a unique population (i.e., individuals working in physically demanding public safety occupations), there is limited previous research on the topic. Most of the previous research concerning aerobic fitness or maximal oxygen consumption (VO_2max), musculoskeletal fitness, and reduced training (i.e., detraining) is concerned with either elite athletes or recently trained individuals. Therefore, the conclusions from this research project were hard to refute or support previous research findings. The best that could be done was to relate our findings to previous research papers that used moderately active or recently trained individuals as their research participants. Future research should further explore physically demanding public safety occupations and the individuals who work in them. Finally, in each of the three research studies, we had limited access to certain data pertaining to the study participants. No qualitative or quantitative data was collected regarding the type of exercise / physical activity the study participants performed during their day-to-day regimes. The lack of this information made it impossible to study our research questions on individual fitness levels. Therefore, the results had to be generalized to the entire study population, even though fitness levels ranged greatly. Future research should aim to collect such data from study participants to explore similar research questions further.

5.2. IMPLICATIONS OF FINDINGS

Manuscript I suggests that individuals should complete a verification phase (VP) immediately following an incremental to maximal graded exercise test (GXT), performed to volitional fatigue, to accurately measure their VO_2max and not just a VO_2 peak. This is especially relevant to any individual whose VO_2max measured during an aerobic fitness test is used to determine whether they meet a job-related aerobic fitness standard required to be hired as a front-line worker. Furthermore, females, older individuals and overweight or obese individuals, whose mean VO_2max values tend to be significantly lower compared to their counterparts, tend to benefit most from the use of a VP. This makes sense, as the fitness standards of bona fide occupational requirements are based on the fitness levels of specific subgroups of individuals, usually females and older individuals, who can complete the critical, physically demanding and frequently occurring job tasks safely and efficiently. The findings of this study are also applicable to any situation in which repeated measurements of VO_2max are taken to establish the efficacy of a training stimulus/physical activity intervention or the impact of pharmaceutical interventions on sport-related or occupational physiological fitness. This is because using a VP immediately after an incremental to maximal GXT ensures that individuals can reach a VO_2 plateau (i.e., VO_2max) and not just a VO_2peak. Individuals who are given a chance to perform a VP immediately after their incremental to maximal GXT, performed to volitional fatigue, can attain significantly higher VO_2max values.

Manuscript II examined the relationships between aerobic fitness, select physical characteristics, simulated job task completion times, and performance scores in structural firefighter applicants to understand better which of these variables is most important to successfully meet the aerobic fitness and simulated job task standards of the SFFA. Male participants had significantly faster completion times for each simulated job task than female participants, and a greater proportion of them met the individual completion time standards plus overall job-related fitness test standards. Those participants who could meet the overall job-related fitness test standard were significantly taller and heavier than those who could not. In addition, successful participants had significantly higher VO_2max values than unsuccessful participants. Finally, sex, height, body mass and aerobic fitness were significantly and negatively correlated to simulated job task completion times and predictive of overall success in the job-related fitness test. Therefore, firefighter applicants must strive to find the right balance between physical characteristics, aerobic training, and musculoskeletal training to meet the required aerobic fitness and simulated job-related fitness test standards successfully. Firefighter applicants can use these results to prepare themselves better to complete the SFFA successfully. Based on their sex, age, height, body mass and VO_2max, applicants should be able to predict their individual simulated job task completion times/performance scores and overall performance score.

Structural firefighter applicants must pass physical and physiological fitness tests before being hired as front-line workers to ensure that they can perform the most physically demanding and often occurring on-the-job tasks safely and efficiently. However, in many cases, structural firefighters do not need to complete annual fitness testing once hired. Manuscript III aimed to examine the effect that short-term reducing training (i.e., detraining) due to the numerous lockdowns associated with the COVID-19 pandemic had on the aerobic fitness and simulated job task performance of structural firefighter applicants. This might provide some insight into the effects of reduced training on the aerobic fitness and simulated job task performance of structural firefighters who discontinue or reduce their regular fitness training / physical activity regime once hired as a full-time front-line workers. This study shows that short-term detraining significantly negatively affects job-related aerobic fitness and the ability to successfully complete the critical simulated job tasks for firefighter applicants, thereby reducing their ability to meet the required job-related standards to be eligible for hire. These results supply support for annual and return-to-work fitness testing for front-line structural firefighters whose safety and job performance depend largely on their physical and physiological fitness. Furthermore, the results from this study can be generalized to any population who works as a front-line worker in a physically demanding public safety occupation (e.g., police, nuclear power workers, wildland firefighters, correctional officers, etc.).

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