University of Alberta

TOWARDS THE DEVELOPMENT OF AN AEROBIC FITNESS STANDARD FOR FIREFIGHTERS

by

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ABSTRACT

Due to the physical demands of firefighting and the public's expectation of protection, it is common for jurisdictions to set physical fitness standards. Tests of fitness are used to assess an individual's capacity to safely and effectively manage the stress of firefighting work. The aim of this thesis was to investigate selected questions regarding the aerobic demands and standards for firefighting.

The first investigation studied the heart rate (HR) responses of students performing physically demanding firefighter training. Results showed that students typically experienced four to six training scenarios a day, ranging from 10:54 to 74:00 min:s in duration. During the various training scenarios, average HR ranged from 55 to 87% of HRmax, with peak values frequently reaching 100% of HRmax, regardless of the type and duration of work.

The second investigation further elucidated the effects of personal protective ensemble (PPE) including the self-contained breathing apparatus (SCBA) on gas exchange during graded exercise (GXT_{PPE}). The main finding from this investigation was a 17.3% reduction in VO_2max during GXT_{PPE}. The difference in VO_2max during the GXT_{PPE} was significantly related to a reduction in ventilation (V_E), which was due to a decreased tidal volume.

The third investigation examined the aerobic demands of a firefighting work simulation (FF Test: Deakin et al., 1996), with specific reference to the 8-min performance standard. In addition, a treadmill protocol to assess the aerobic fitness for firefighters was examined. Coincidence analysis revealed there was no difference in slope and intercept between the male and female regression lines; and they were therefore collapsed. The resulting equation showed that the VO_2 associated with the 8-min standard was 34.1 $ml•kg^{-1}•min^{-1}$, which is consistent with the literature. It was also found that the aerobic demands could be replicated, without gender bias, using a constant workload treadmill test.

Results from this research underscore the need for aerobic fitness screening for firefighting; the assessment of aerobic fitness should take into account the effects of the PPE. Finally, the aerobic demands of the FF Test and subsequent treadmill test provided a novel approach to assessing the aerobic fitness for male and female firefighters.

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DEDICATION

To my life partner, support system and friend

Holly Ann Dreger

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol/Abbreviation	**Definition**
BFOR	- *Bona fide* occupational requirement
f	- Breathing frequency
F_EO_2	- Fraction of expired oxygen
F_ECO_2	- Fraction of expired carbon dioxide
GXT	- Graded exercise test
HRR	- Heart rate reserve
HRmax	- Maximum heart rate
PPE	- Personal protective ensemble
PRD	- Perceived respiratory distress
PTD	- Perceived thermal distress
RER	- Respiratory exchange ratio
RPE	- Rating of perceived exertion
SCBA	- Self-contained breathing apparatus
VCO_2	- Volume of carbon dioxide production
V_E	- Minute ventilation
VO_2	- Volume of oxygen consumption
VO_2max	- Maximal volume of oxygen consumption
V_T	- Tidal volume

CHAPTER 1

INTRODUCTION

1.1 Background Information

Most authorities acknowledge that firefighting ranks among the most physically demanding occupations, and even a rudimentary survey of the job demands would provide support for this conclusion (Gledhill and Jamnik, 1992a; Lemon and Hermiston, 1977; NFPA, 2003). Many fire suppression duties involve a significant amount of manual labor with heavy tools and equipment. For example, firefighters are often required to move heavy tools and equipment (e.g., hoses and ladders) to the point of attack and then work with them. In addition, the average firefighter carries approximately 22 kg of protective clothing and self-contained breathing apparatus (SCBA), which increases the metabolic, cardiovascular, pulmonary and thermal load on the individual (Eves et al., 2002; Louhevaara et al., 1985; Skoldstrom, 1987). In many cases firefighters must do their work under very hostile environmental conditions (e.g., heat, smoke, darkness, ice), which makes the work more difficult and magnifies the physical stress (Smith et al., 1996). Finally, firefighters are frequently required to combat dangerous emergencies where life and property are threatened. In cases where response time is critical, the physical stresses noted above are further amplified by the requirement for speed (Sothmann et al., 1990).

Considering the demands of the job and public expectations for protection, it is understandable that most fire service jurisdictions set physical requirements for applicants (Brownlie et al., 1985). Logically, applicants must demonstrate the capacity to manage the physical stresses of the job before being entrusted by the public and their fellow firefighters to undertake this important emergency response function. In most jurisdictions, applicants must pass a physical fitness test as part of the selection process (Considine et al., 1976; Davis and Dotson, 1987a, 1987b; Misner et al., 1989). The tests and performance standards must be sufficiently sensitive to identify those applicants who physically can and cannot do the job (Roberts et al., 2002).

1.2 Firefighter Training

Before an individual can undertake fire service duties, it is necessary that they complete a series of training courses to acquire the requisite skills involved in fire suppression (NFPA, 1997). Typically, training courses are designed to replicate emergency situations in a controlled setting. Many of the scenarios involve the use of live fire, which increases both the danger and the physical stress. Another characteristic of live fire training is that students frequently perform a number of repetitions of the scenario in a short time period. This type of situation is probably less likely in the "real world" of fire suppression, but is very typical of training for two reasons. First, repetition is often required for mastery of the specific skills. Second, firefighting normally involves teamwork, and multiple repetitions of training scenarios allow students to participate in the different aspects of the team approach to fire suppression (Romet and Frim, 1987). In some courses, several types of scenarios are presented to students in relatively short periods of time. Consequently, the physical stress of training may exceed the physical stress that is normally encountered by career firefighters. There is a paucity of information describing the physiological demands of firefighter training, making it difficult to prescribe physical fitness standards for entry.

1.3 Bona Fide Occupational Requirements and Firefighting

Physical standards may be legitimately used as entry criteria; however it is very important that the standards by which applicants are judged be fair and reasonable (Government of Canada, 1988). A standard that is too harsh may eliminate qualified applicants. Similarly, a standard that is too lenient may have the effect of admitting applicants who lack the physical capacities to work effectively and/or safely (Gledhill et al., 2001). Some tests and/or standards could incorporate biases (e.g., gender, age or ethnicity) that prevent otherwise qualified applicants from being fairly evaluated. If the tests and standards incorporate such biases then the result could be a breach of human rights legislation (Government of Canada, 1988). Standards must be reasonable, must reflect the actual demands of the job, must be free from bias, and must be created and implemented in good faith (Government of Canada, 1988).

Identification of relevant fitness components is an important step in the development of fitness standards (Gledhill et al., 2001). However, the final selection of the specific tests and the standards by which performance is judged must be based on the best possible understanding of the physical requirements of the job. In other words, it is not enough to simply test a relevant fitness component. The method chosen to assess the component must be related to the way in which the component of fitness is used on the job. Furthermore, the minimal standard of acceptability must be consistent with the minimal acceptable levels of performance and safety (Gerkin, 1995).

Firefighters normally work while carrying the burden of protective clothing and the SCBA, performing common tasks including carrying equipment, advancing charged hose and ladder climbing, for extended periods (Gledhill and Jamnik, 1992a, 1992b). Based on the activities described, the relevance of strength and cardiovascular fitness is likely to be undisputed (NFPA, 2003). However, the manner in which these components are tested could well be challenged if the test protocol does not reflect the requirements of the job task and/or the standard does not reflect reasonable performance or safety expectations (Eid, 2001; Shephard, 1990).

In the final analysis, the test results should facilitate confident selection of those applicants who have the physical characteristics to proceed into fire training. Many of the specific tasks on the job are correctly executed through a blend of physical, biomechanical, and cognitive traits. Applicants should not normally be expected to demonstrate those skills that are typically acquired over years of training and experience. At the same time, the test results should be capable of eliminating those applicants who lack the physical attributes required to complete fire training safely and effectively.

1.4 Aerobic Fitness Standards

Aerobic fitness is an important component for firefighters (Davis and Dotson, 1987a, 1987b; Gledhill and Jamnik, 1992a NFPA, 2003; Romet and

Frim, 1987); however, this physiological attribute cannot be easily and accurately measured during job simulation testing. In order to set a minimum aerobic fitness standard, such as VO_2max, one must first determine the oxygen cost (VO_2) associated with firefighting work (Sothmann et al., 1990). Several methods have been employed in an attempt to determine the oxygen cost of firefighting work. Direct measurement of VO_2 during actual emergencies is the most accurate method, however this is very difficult to accomplish. The utility of this approach is limited by: the expense and technical requirements of the necessary equipment; the potentially disruptive effects on execution of fire suppression duties when public safety is at risk; and, the environmental limitations of the instrumentation (e.g., inability to operate in high temperatures and smoke). Therefore, direct measurement of oxygen uptake has normally been performed under simulated firefighting conditions (Sothmann et al., 1990; Bilzon et al., 2001; von Heimburg, 2006).

Several studies have reported the oxygen cost of fire suppression activities in an attempt to define the work load associated with firefighting, which is then used to determine a minimum VO_2max standard necessary for firefighters to safely and effectively meet the demands of firefighting work. VO_2max is well established as the "gold standard" for assessment of cardiovascular and aerobic capacity (Sutton, 1992). The recommended minimum VO_2max ranges from 33.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (Sothmann et al., 1990) to 48 $ml \cdot kg^{-1} \cdot min^{-1}$ (von Heimburg et al., 2006). Although it may appear that the issue of a minimum VO_2max standard has been adequately addressed in the literature, there are some possible flaws in the methodology of the previous research, where investigators have failed to adequately account for the effects of the protective equipment and the SCBA on oxygen consumption during the determination of the work load or the capacity of the worker. Furthermore, there is evidence that the majority of firefighting work is performed at submaximal efforts for extended periods of time (Davis and Dotson, 1978; Gledhill and Jamnik, 1992; Lemon and Hermiston, 1977, Lusa et al., 1993; O'Connell et al., 1986; Sothmann et al., 1990; Sothmann et al, 1991). Therefore, it may be more suitable to assess a firefighter's ability to sustain a particular workload. The Department of National Defence have implemented the use firefighting work circuit (FF Test) composed various common firefighting tasks performed in succession which are reflective of the demands fire emergencies (Deakin et al., 1996). In addition, wildland firefighting has taken this approach by initiating the wildland firefighter work capacity test otherwise know as the "Pack Test" (Sharkey et al., 1995).

1.5 Females and Firefighting

Many studies (Davis and Dotson, 1978; Gledhill and Jamnik, 1992; Lemon and Hermiston, 1977, Lusa et al., 1993; O'Connell et al., 1986; Sothmann et al., 1990; Sothmann et al, 1991; von Heimburg et al., 2006) have been undertaken to determine the minimum aerobic demand required to perform firefighting (FF) tasks. To date, only one study (Bilzon et al., 2001) has involved females as part of their investigation into the aerobic responses of firefighter activities. Consequently, the aerobic demands of firefighting work and the subsequent fitness standards that have arisen from previous research are based solely on male observations. With an increasing number of women applying to the fire trade and the possible physical and physiological differences between males and females (Shephard, 1990; Shephard and Bonneau, 2002), it is imperative that oxygen cost responses of females performing firefighter tasks be undertaken to ensure compliance with current legislation (Shephard and Bonneau, 2002).

1.6 Statement of Purpose

To ensure an appropriate match between a firefighter (worker) and the demands of firefighting (workload) a series of steps are required. First, the determination of the physical stresses involved with firefighting is needed with particular reference to the oxygen cost of the activities. Second, it is necessary to appropriately assess the firefighter. To some extent, issues related to workload as well as assessment of firefighters has been examined, however, there remain unanswered questions, particularly due to an under-representation of female responses to firefighting activities. Such gender issues need to be examined in order to comply with governmental legislation.

The Canadian Forces have recognized the importance of such issues and entered into a contractual agreement with The University of Alberta (U of A) to conduct research into the development of *bona fide* physical fitness selection standards. Some of the research contained in this dissertation was part of a larger project, which produced the Canadian Forces/Department of National Defence Fire Fighter Applicant Test (Petersen and Dreger, 2006).

Project One – Heart Rate Responses to Firefighter Training

Purpose

Based on the paucity of scientific data describing the physical demands of firefighting training, an initial study (Chapter 3) was designed to:

1. Identify the training courses and activities which imposed a significant physical demand on firefighting students; and,
2. Characterize the cardiovascular and psychophysical responses of students undertaking the identified physically demanding training courses and activities.

Hypotheses

This project utilized a non-hypothesis approach, as the intent was to describe the physiological and psychophysical responses of students during firefighter training activities.

Project Two – Effects of the Self-contained Breathing Apparatus and Fire Protective Clothing on Maximal Oxygen Uptake

Purpose

In order to address issues pertaining to the effect of personal protective equipment (PPE) and the self-contained breathing apparatus (SCBA) on the assessment of aerobic fitness, a project (Chapter 4) was undertaken to investigate the combined effects of PPE and the SCBA on gas exchange (oxygen consumption and carbon dioxide production), pulmonary function (ventilation, breathing frequency and tidal volume), and cardiac responses (heart rate).

Experimental Hypotheses

1. The PPE condition would demonstrate a significantly lower VO_2max value compared to the PT condition.
2. Oxygen cost during submaximal exercise would be significantly greater during the PPE condition.
3. At maximal exercise, peak pulmonary ventilation would be significantly lower during the PPE condition compared to the PT condition.
4. Reduction in VO_2max during the PPE condition would be significantly related to the reduction in pulmonary ventilation.

Project Three - Evaluation of the Aerobic Demand of the FF Test and Development of a Treadmill Test for Firefighters

Purpose

The final project (Chapter 5) was designed to develop an aerobic fitness standard and assessment for firefighters by:

1. Characterizing the cardiorespiratory responses (oxygen consumption, carbon dioxide production, ventilation, breathing frequency, tidal volume, and heart rate) during the FF Test;

    a. Calculating the oxygen cost associated with completing the FF Test at the 8-min standard;
    b. Examining both the cardiorespiratory and oxygen consumption data for potential gender differences;
2. Examining the potential of a treadmill test for the assessment of aerobic fitness for firefighters.

Experimental Hypotheses

1. The oxygen cost required to perform the FF Test would be significantly related to performance time.
2. Regression equations developed to predict the oxygen cost of the FF Test would be the same for males and females.
3. The VO_2 values when performing the 8-min constant work phase of the treadmill test would be the same for males and females.

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CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

For more than 30 years, various aspects of firefighting such as the physiological, environmental, and psychological have been studied (Barnard and Duncan, 1975; Guidotti and Clough, 1992; White et al., 1991). Research has concluded that firefighting is considered among the most physically demanding occupations (Gledhill and Jamnik, 1992b), and it is estimated that up to 50% of firefighting work can be classified under the "physical" domain with the remaining being "mental" (Kenney et al., 1993). In contrast, police work is less "physical" and more "mental" (19% physical and 81% mental) (Kenney et al., 1993). Characterization of the physical demands of firefighting is of the utmost importance in defining the level of fitness required to perform the job safely and effectively.

2.2 Physiological Demands of Firefighting

2.2.1 Heart Rate Response to Firefighting

In order to reflect the work load during various activities, researchers have utilized heart rate recordings (Astrand and Rodahl, 1986). Due to the harsh environment firefighter's encounter, measuring heart rate responses during firefighting work has been one of the primary means of classifying the demands of firefighting. Although a number of methods are available for the interpretation of raw heart rate responses, the most common form has been average and peak heart rate responses as well as a percentage of maximum heart rate (Louhevaara et al., 1994; Petersen et al., 2000; Davis et al., 1982)

For more than two decades, researchers have studied the heart rate responses under a variety of conditions from individual tasks to actual emergencies. The most valid means of determining the physical demands of firefighting would involve physiological monitoring of firefighters during actual emergencies. However, a number of logistical constraints make this difficult. Barnard and Duncan (1975) examined the heart rates from 35 experienced firefighters responding to a total of 189 alarms. The results of there study were categorized as “immediately post-alarm” and “during fire fighting”. The heart rate response immediately post-alarm showed an average increase of 47 beats•min^{-1} (range 12 to 117 beats•min^{-1}). The results obtained during actual firefighting activities showed that very high heart rates (175 to 195 beats•min^{-1}) were achieved. In a similar study, Kuorinka and Korhonen (1981) examined the heart rate responses of 22 firefighters during 60 alarms. The initial rise in heart rate, upon hearing the alarm, averaged 61 beats•min^{-1}. Unfortunately, they did not report the heart rate responses during firefighting activities. In a more recent study (Sothmann et al., 1992) examined the heart rate responses of 10 male firefighters during a single fire emergency call. The average heart rate response was 157 (± 8) beats•min^{-1} (range 146 to 171 beats•min^{-1}). The average work duration during the emergency was 15 min (8 to 28 min). Of even more interest, the heart rate responses averaged 88% of the maximal heart obtained during a graded exercise treadmill test.

Due to the limited information from actual emergencies, investigators have measured heart rate responses during activities that recreate the physical demands of firefighting. One method that has been utilized, has subject performing a series of individual firefighting tasks sequentially, which is often referred to as a circuit. The primary purpose for using a circuit is to more closely simulate the demands encountered at a fire scene. A variety of circuits have been developed to simulate fire suppression activities both with and without live fires. Among the studies that have utilized the circuit format, many have involved certain commonalities. The subjects have included civilians (Schonfeld et al., 1990), actual firefighters (Davis et al., 1982; Louhevaara et al., 1994) or a combination (Petersen et al., 2000). In each case, the subjects studied wore standard firefighting protective equipment (approximate weight of 22 to 25 kg) including a self-contained breathing apparatus (SCBA). In addition, the subjects were breathing from the SCBA while performing the circuit. Typically subjects were required to perform the tasks within the circuit as quickly as possible (Schonfeld et al., 1990; Petersen et al., 2000; Davis et al., 1982), while others Louhevaara et al., 1994) used a pacing system. The most common firefighting tasks used in the circuits involved hammering/chopping, stair/ladder climbing, victim rescue, rope pulling, and carrying equipment. The results of the various studies are summarized in Table 2-1.

Table 2-1. Heart rate response of various firefighting circuits without fire.

Reference	Duration (min)	Heart Rate (beats•min^{-1})
Louhevaara et al., 1994	14.5	140
Schonfeld et al., 1990	3.6	175
Petersen et al., 2000	5.4	173
Davis et al., 1982	7.0	169

To further simulate the demands of an actual fire scene, many investigations have utilized a circuit format with the addition of live fire either as a part of the circuit or to provide heat and smoke (Romet and Frim, 1987; Lusa et al., 1993; Smith et al., 2001; Smith and Petruzzello, 1998; Sothmann et al., 1990). In these investigations, subjects were either firefighter students (Lusa et al., 1993; Smith et al., 2001) or actual firefighters (Romet and Frim, 1987; Smith and Petruzzello, 1998; Sothmann et al., 1990). All subjects wore standard firefighting protective equipment and breathed from the SCBA. Typically, subjects were required to perform the tasks within the circuit as quickly as possible. The most common firefighting tasks used in the circuits involved hammering/chopping, stair/ladder climbing, victim rescue, rope pulling, and equipment carrying. The mean circuit performance time ranged from 6 to 28 minutes with heart rates ranging between 140 to 179 beats•min^{-1} (Table 2-2).

Table 2-2. Heart rate response to firefighter circuits with fire.

Reference	Duration (min)	Heart Rate (beats•min^{-1})
Romet and Frim, 1987	28	131
Lusa et al., 1993	17	150
Smith et al., 2001	21	183
Smith and Petruzzello, 1986	6.1	175
Sothmann et al., 1990	8.9	173

Another method used to examine the heart rate response related to firefighting has involved the use of individual firefighting tasks. However, there are some limitations to this type of information: rarely do firefighters perform a single task at a live fire scene; tasks performed in isolation may be performed differently than if they were done after a series of other tasks; and, the duration of the task(s) may be to short in duration to be reflected by heart rate response. Regardless, a number of investigations have utilized this methodology. Lemon and Hermistion (1977) examined the responses of 10 experienced firefighters during aerial ladder climb, victim rescue, hose drag, and ladder raise. The mean heart rate responses ranged from 115 to 157 beats•min^{-1} these activities lasted from 31 and 134 s. Gledhill and Jamnik (1992a) examined 25 individual tasks and the associated heart rate responses. A summary of the results indicated that the mean heart rate response to the individual tasks ranged from 106 to181 beats•min^{-1}. The duration of the tasks lasted from 17 to 239 s.

Based on the studies of heart rate, it is evident that firefighting imposes a significant strain on the cardiac system. Myocardial infarction (MI) has been the leading cause of death among on-duty fire fighters (Barnard, 1979; Washburn et al., 1998). Between 1993 and 1997 MI accounted for 34 to 51% of all firefighter deaths (Washburn et al., 1998). In comparison to other occupations, the epidemiological evidence strongly suggests an increased risk of death from heart disease among firefighters (Choi, 2000). This is of particular interest since firefighters typically undergo stringent health screening protocols prior to selection (NFPA, 2003). It is therefore, important that fire fighters are physically capable of withstanding this strain.

2.2.2 Aerobic Demands

The energy demands of firefighting work are of interest for a number of reasons. First and foremost, it is necessary to understand the energy cost to safely and effectively complete the work. Second, many researchers have used maximal oxygen consumption (VO_2max) to identify an aerobic standard that firefighters must attain in order to safely and effectively meet the demands of the work.

Several methods have been employed in an attempt to determine the oxygen cost of firefighting work. Direct measurement of VO_2 during actual emergencies would, in theory, be the most accurate method, however this is very difficult to accomplish. The utility of this approach is limited by: the expense and technical requirements of the necessary equipment; the potentially disruptive effects on execution of fire suppression duties when public safety is at risk; and, the environmental limitations of the instrumentation (e.g., not designed for high temperatures and smoke). Therefore, direct measurement of oxygen uptake has normally been performed under simulated firefighting conditions. Published literature on the oxygen cost of simulated firefighting work has included: simulated smoke-diving (Lusa et al., 1994); simulated fire scenarios (Sothmann et al., 1990; 1992b); individual task performance (Lemon and Hermiston, 1977b; Gledhill and Jamnik, 1992a); simulated rescue (von Heimburg et al., 2006); and, simulated shipboard firefighting (Bilzon et al., 2001).

One of the first studies to examine the oxygen cost of firefighting utilized the Douglas bag method to directly measure the VO_2 of incumbents performing selected firefighting tasks (ladder climb, victim rescue, hose drag and ladder raise) in a safe and effective manner (Lemon and Hermiston, 1977b). Each of the firefighters wore standard turnout gear while performing the tasks. The results of the study indicated that the selected firefighting tasks required a VO_2 of 2.19 to 2.55 $L \bullet min^{-1}$. Using the demographic data reported in this study, the VO_2 relative to body mass was calculated to be 26.1 to 30.7 $ml \bullet kg^{-1} \bullet min^{-1}$. Due to the relatively short duration of the fire fighting tasks the reported oxygen cost may not be reflective of the actual demands.

O'Connell et al., (1986) measured the oxygen cost of simulated stair climbing in 17 firefighters. The firefighters were dressed in turnout gear and carried a length of hose over their shoulder. The mean VO_2 observed during 5 minutes of exercise at a stepping rate of 60 $steps \bullet min^{-1}$ was 38.6 $ml \bullet kg^{-1} \bullet min^{-1}$.

Gledhill and Jamnik (1992a) also used the Douglas bag method to measure the VO_2 of incumbent firefighters while performing a variety of firefighting tasks. Subjects performed the tasks in standard turnout gear including SCBA (without breathing from it) under 'emergency-like' conditions. These investigators reported that the average oxygen cost of 90% of the tasks analyzed required a VO_2 of 23.4 ml•kg^{-1}•min^{-1} (range: 16.8 to 44.0 ml•kg^{-1}•min^{-1}). In the final analysis, the authors recommended that the most significant oxygen consumption values were obtained from the tasks that were most physically demanding and most frequently encountered. The mean VO_2 for these tasks was 40.7 ml•kg^{-1}•min^{-1}, and the corresponding work time was 2.35 minutes. One of the shortcomings of this research was that the tasks were performed in isolation. While this approach provided an accurate determination of the VO_2 required for each individual task, it did not allow for an accurate estimation of the VO_2 required for fire suppression work that involves a series of tasks or alternately, prolonged work on one task.

One of the best investigations of the oxygen cost of firefighting studied incumbent firefighters during a firefighting scenario in a hot, smoke-filled environment that replicated the demands of a live-fire emergency (Sothmann et al., 1990). Oxygen consumption was directly measured utilizing a metabolic measurement system integrated with the SCBA. Subjects were requested to perform the scenario in a manner similar to an actual emergency. It was reported that the scenario required absolute and relative oxygen consumption rates of 2.5 L•min^{-1} (range: 1.7 to 3.7 L•min^{-1}) and 30.5 ml•kg^{-1}•min^{-1} (range: 23.5 to 49.3

ml•kg^{-1}•min^{-1}), respectively. The corresponding average completion time was 8.93 minutes.

Lusa et al. (1993) estimated VO_2 during a live-fire scenario by measuring the volume of air consumed from the SCBA cylinder. This method relies on some assumptions about respiratory gas exchange and consequently it is important to treat the results as estimates rather than measurements. The oxygen cost for the scenarios was estimated to be 2.4 L•min^{-1} (range: 1.8 to 4.3 L•min^{-1}) or 31 ml•kg^{-1}•min^{-1} (range: 22 to 55.0 ml•kg^{-1}•min^{-1}).

In a recent study (von Heimburg et al., 2006) a group of firefighters completed a simulated rescue of hospital patients. The task involved climbing a set of stairs (20.5 m vertical ascent) while carrying standardized equipment (fire hose, axe and flashlight, 37 kg). The subjects then set down the equipment and performed six patient rescues (two patients were dragged 17 m, two were dragged 22 m, and two were dragged 42 m). The average completion time was 6.58 min (range 5 to 9 min). The average oxygen cost observed during the task was 33.8 ml•kg^{-1}•min^{-1} (2.80 L•min^{-1}).

In contrast to the relative abundance of research describing the aerobic requirements of firefighting work in males, there has been only one study published in the scientific literature that examined the VO_2 responses of females during simulated firefighting work (Bilzon et al., 2001). This investigation studied 34 male and 15 female Royal Navy personnel who had a minimal level of shipboard firefighting training (3 days). Each subject performed five firefighting activities while dressed in appropriate ensembles of protective equipment. Each of the five activities was meant to be completed at a prescribed work-rate for 4-minutes. The activities were:

- Boundary cooling (BC) – this activity involved operating a charged hose for a total work time of 4-min;
- Hose running (HR) – this activity involved reeling out 12.3 m lengths of hose (7.1 kg) for a total time of 4-min;
- Ladder climbing (LC) – subjects entered a hatch and descended a vertical distance of 2.8 m with a charged hose (approximately 10 kg). The subjects then released the hose, walked 14 m and ascended a ladder (vertical height 2 m) to the start position. Each subject completed 6 circuits within a 4-min period;
- Extinguisher carry (EC) – subjects carried a liquid foam extinguisher (11.2 kg) along a predetermined route that included ascending two external sloping ladders (total vertical height of 4 m), walking across a horizontal deck (17 m), descending the ladders, and walking back to the start point. Each subject undertook 4 circuits of this route at a controlled work-rate of one circuit per minute; and,
- Drum carry (DC) – subjects carried liquid foam drums (30 kg) from the start point to the firefighting team in a lower-engine space at a rate of 1 drum per minute. In this scenario, each 'delivery' involved carrying the drum down two sloping ladders (total vertical height of 4 m) and walking 25 m. The subject then put the drum down and returned to the start point.

Respiratory gas exchange data were recorded using a VmaxST (SensorMedics, Yorba Linda, CA) portable metabolic measurement system. The oxygen cost (average for all subjects) for the various firefighting activities ranged from 23 ± 6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$for the boundary cooling to 43 ± 6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$for the drum carry. The mean oxygen cost to perform all of the fire suppression activities described in this experiment was approximately 34 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$.

There were no significant gender differences in the oxygen cost of doing the work in the BC, DC, or HR activities. However, the aerobic cost of the work was significantly higher for the males during the EC and LC tasks. When the oxygen cost of the work was expressed as a percentage of the VO_2max, this pattern was reversed. The mean VO_2max of the males and females was 53 ± 5 and 43 ± 6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, respectively. Consequently, when expressed as a percentage of the VO_2max, the oxygen cost of the EC task was 76 and 86% for males and females, respectively. In other words, the females were required to work at a greater fraction of their maximal capacity in order to do the work at the prescribed rate.

It is of interest that 11 of the 15 females 'failed to maintain the endorsed work-rate' in the DC task. The females who did complete the task at the acceptable work-rate demonstrated a level of oxygen consumption during the task consistent with the average VO_2max for all the female subjects. That is, the aerobic demand of the DC task for the four successful females was 42 ± 6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, while the average VO_2max for all the female subjects was 43 ± 8 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$.

The results of this study reported the mean oxygen cost for females and males performing simulated firefighting work to be 33 to 34 ml•kg^{-1}•min^{-1}, respectively with a range of 23 to 42 ml•kg^{-1}•min^{-1}. This is similar to most of the values reported in the literature for males, but it is important to recognize that the number of females studied was very small (n=4) on the most demanding activity (DC), so the results should be interpreted with some degree of caution. With this one exception, the study by Bilzon et al. (2001) was well-designed, and the data are both interesting and valuable. However, one might question whether the results would apply to structural firefighting where the activities are somewhat different.

By averaging the VO_2 data reported in the literature (O'Connell et al., 1986; Sothmann et al., 1990, 1992a; Gledhill and Jamnik 1992a; Lusa et al., 1993; Bilzon et al., 2001; von Heimburg et al., 2006), the mean oxygen cost of fire suppression and rescue work appears to be approximately 32 ml•kg^{-1}•min^{-1} (range: 16 to 55 ml•kg^{-1}•min^{-}1 or 1.7 to 4.3 L•min^{-1}).

At first glance, it may be tempting to speculate from the broad range of oxygen consumption values that scientists cannot make up their minds about the VO_2 associated with firefighting work. However, it is very important to bear in mind several important points when reviewing these values. First, there is a fundamental inverse relationship between intensity and duration of exercise. Second, experienced workers will tend to pace themselves at a level consistent with completing the work at hand (Manning and Griggs, 1983). Thirdly, sensory restriction (e.g., smoke and darkness) necessitates that the average work-rate be reduced. If a worker cannot see the object of the search, then he or she must slow down in order to search "by feel". This process includes aspects of actual searching as well as maintaining spatial orientation in the search area. Variability in research design has led to the wide variability in observed VO_2. For example, the work-rate could be dictated by the investigators (O'Connell et al., 1986; Bilzon et al., 2001) or self-selected by the subjects (Sothmann et al., 1990; Gledhill and Jamnik, 1992b; von Heimburg et al., 2006). Alternately, the subjects may have been given a discrete task and directed to complete it as fast as possible (Gledhill and Jamnik, 1992b) or, a series of tasks complicated by sensory deprivation (Sothmann et al., 1990). Finally, some techniques are more precise than others. For example, Bilzon et al., (2001) directly measured respiratory gas exchange while Lusa et al., (1993) estimated oxygen consumption from measurements of air consumption. Review of the unique aspects of each research design is required prior to interpreting the values. Despite the apparently large number of studies that have tried to document the aerobic demands of firefighting work, there is actually very little consistency between research design factors. Therefore, each data set must be judged on its own merit. However, when combined, these studies can provide general insight into the oxygen cost of firefighting work.

Once the oxygen cost of firefighting work has been determined, the next step in the development of an aerobic fitness standard can be undertaken. It is important to note there is an inverse relationship between intensity of work (e.g., VO_2) and the total work time at that intensity (Astrand and Rodahl, 1986). In humans the fraction of maximum oxygen consumption is commonly utilized as a means of describing workload and thus work-time. Astrand and Rodahl (1986) has described permissible working times associated with various fractions of VO_2max. For example, a healthy, physically active individual could exercise for a relatively long time (e.g., 60 min) at an intensity of 60% of his/her VO_2max. However, as the intensity of work increases, the exercise time decreases. An individual might be able to work for 30 min at 75% of VO_2max, 10 min at 85% of VO_2max, and 3 min at 95% of VO_2max. The values for time and intensity for any given individual are usually dependent on the level of training and may vary between individuals. The values given above are estimates provided for the purposes of illustrating the relationship between work intensity and the time that specific work-rates may be sustained. Louhevaara et al. (1986) demonstrated that a similar relationship exists when exercising with the SCBA.

Because the work duration/intensity relationship exists, scientists have suggested specific VO_2max values that would allow firefighters to work at the expected intensity of firefighting work for an appropriate amount of time. Since the VO_2max is universally recognized as an important measurement of physical fitness and is relatively easy to measure, researchers have used this physiological variable to set fitness standards for workers. Recommendations for minimum VO_2max described by various authors range from 33.5 to 48 $ml \cdot kg^{-1} \cdot min^{-1}$ (Bilzon et al., 2001; Davis and Dotson, 1987b; Gledhill and Jamnik, 1992a; Lemon and Hermiston, 1977, Lusa et al., 1993; O'Connell et al., 1986; Sothmann et al., 1990; Sothmann et al., 1991; von Heimburg et al., 2006).

Previous recommendations regarding the minimum VO_2max standard have typically measured oxygen consumption during graded exercise tests (GXT) on a cycle ergometer or treadmill, with the subjects wearing shorts and t-shirt (Gledhill and Jamnik, 1992b).

Table 2-3. Reported maximal oxygen consumption (VO_2max) of male firefighters.

Reference	Age (yr)	VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	VO_2max ($L \cdot min^{-1}$)
Byrd and Collins, 1980	34.6	34.0	2.85
Davis et al., 1982	33.1	39.6	3.28
O'Connell et al., 1986	32.3	48.4	3.97
Louhevarra et al., 1986	30.0	57.0	4.16
Sothmann et al., 1990	N/A	34.7	N/A
Gledhill and Jamnik, 1992	30.4	48.7	3.97
Sothmann et al., 1992	32.0	40.0	3.70
Deakin et al., 1996	30.7	48.9	4.19
Malley et al., 1999	43.0	47.0	3.76

N/A = not reported. Oxygen consumption was directly measured in each study.

Table 2-3 summarizes the reported VO_2max values for firefighters utilizing standard measurement techniques. The subjects wore traditional exercise clothing (shorts and t-shirt), while exercising on a treadmill or cycle ergometer.

Herein lies one issue, assessing firefighters in traditional exercise clothing is a divergence from the protective equipment worn by firefighters while working on the job. Previous research has demonstrated that the PPE and the SCBA, alone or in combination has a negative impact on work performance and VO_2max (Raven et al., 1982; Louhevaara et al., 1986, 1995). To account for the impact of the firefighter ensemble and SCBA some assessments have "embedded" the aerobic component into simulated firefighting tests (Louhevaara et al., 1994; Deakin et al., 1996) however, neither of these tests have directly measured oxygen consumption to confirm whether the level of VO_2 required to complete the activity is consistent with firefighting.

As noted previously, the energy demands of firefighting work are of interest for a number of reasons. First and foremost, it is necessary to understand the rate of energy production that must be sustained in order to safely and effectively complete the work. Second, many researchers have used this data in order to identify a minimum VO_2max standard necessary for firefighters to safely and effectively meet the demands of the work. However, these standards have not adequately addressed issues related to the impact of the SCBA and PPE. In addition, with the exception of Bilzon et al. (2001), the previous research has utilized male subjects. Consequently, descriptions of the aerobic demands of firefighting and suggested fitness standards from previous research are based on male performance. The aerobic demand on females performing firefighting tasks has not been adequately documented in the scientific literature. Given the general physical and physiological differences between males and females, it seems prudent to determine whether these differences influence the energetics of firefighting work.

2.2.3 Anaerobic Demands

The contribution of energy from the anaerobic pathways is considered an important factor in firefighting; however, there is a paucity of research examining this component. There is no literature describing the anaerobic demands during actual emergencies. Therefore information has been limited to the responses induced by firefighting simulations. One method of determining the anaerobic component is via blood lactate analysis. Petersen et al. (2000) examined the blood lactate responses of subjects after they performed a series of fire-related tasks; the average blood lactate was 15.57 mM/L. In a similar investigation (Deakin et al., 1996), 23 firefighters performed a 10-item firefighter circuit with an average performance time less than seven minutes with a corresponding mean post-circuit blood lactate value of 16 mM/L.

The only other investigation that has measured blood lactate responses to firefighting activities was Gledhill and Jamnik (1992a). They recorded blood lactate levels after firefighters performed three individual fire suppression tasks. The responses for rope pulling (approximately 92 seconds) was 7.2 mM/L (6.0 to 9.6 mM/L); hose carry/climbing, which averaged 128 seconds was 10.0 mM/L (7.9 to 13.2 mM/L); and, victim carry with an average performance time of 17 seconds was 9.2 mM/L (8.5 to 12.2 mM/L). According to Astrand and Rodahl (1986) these results would range from moderate to high.

In addition to measurement of blood lactate, investigators have examined the relationship between firefighting activities (e.g., hose drag, victim rescue) and laboratory tests of "anaerobic" power and capacity (e.g., 30 second Wingate). Relatively low (r = -0.14 to -0.36) non-significant correlations between standard power tests and task-related tests have been reported (Jaenen, 1994; Schonfeld et al., 1990).

Table 2-4 summarizes the anaerobic power and capacity characteristics of firefighters from the literature. The peak and mean leg power output for females tend to be similar to normative data (Findley et al. 2002). Male firefighters tend to have similar results to males in other demanding professions.

Table 2-4. Anaerobic power characteristics of firefighters.

Reference	L-PPO (W/kg)	L-MPO (W/kg)	A-PPO (W/kg)	A-MPO (W/kg)
Findley et al., 2002*	6.75	4.70	N/A	N/A
Misner et al., 1988*	7.79	6.28	N/A	N/A
Schonfeld et al.,1990	6.57	N/A	3.32	N/A
Jaenen, 1994	13.6	10.5	5.76	4.81

L = leg; A = Arm; PPO = peak power output from a 30 second Wingate test; MPO = mean power output from a 30 second Wingate test; * = females.

2.2.4 Muscular Strength and Endurance Demands

It is well recognized that firefighting requires a great deal of muscular strength to move and use equipment as well as muscular endurance to repeatedly perform actions such as chopping and holding a hose line. There is limited information regarding the strength characteristics of firefighters. The available information is typically limited to general strength parameters. In addition, the tests that have been utilized usually do not replicate the movement patterns of the job requirements. Table 2-5 presents the strength characteristics of firefighters.

Table 2-5. Selected muscular strength and endurance characteristics of firefighters.

Reference	Grip (kg)	Sit-ups (reps)	Push-ups (reps)	Pull-ups (reps)	Leg Press (reps)
Davis et al., 1982	47+	37	19	6	N/A
Deakin et al., 1996	114	41	37	7	N/A
Lu, 1999	114	107	N/A	9	28*
Rhea et al., 2004	59+	79	N/A	N/A	N/A
Williford et al., 1999	117	40	41	N/A	N/A

+ = right hand only. * = 80% of 1 repetition maximum.

Characterization of the strength requirements of firefighting has typically been based on the weights and measures of tools and equipment commonly used in firefighting. Gledhill and Jamnik (1992a) provided one of the most extensive analyses of the common weights and forces required for firefighting work. They found that objects handled by a single firefighter ranged in weight from 3.6 to 29 kg; Deakin et al. (1996) reported similar results (4.1 to 36.4 kg).

In one investigation, the forces required to move equipment, raise ladders, lower victims, ranged from 32 to 54 kg (Gledhill and Jamnik, 1992a). Another study found the force required to extend ladders, move charged hoses, and start various equipment ranged from 222 to 489 N (Deakin et al., 1996).

There is evidence (Lu, 1999; Williford et al., 1999) that significant correlation coefficients exist between specific muscular strength and endurance tests (e.g., push-ups, pull-ups) and job-related performance tests (e.g., hose advance, forcible entry). However, correlation coefficients typically range from .30 to .59, depending on the nature of the testing batteries. Whereas, strength and endurance tests which have utilized a resistance (e.g., bench press, squat endurance) show much higher relationship, with correlation coefficients as high as -0.85 (Rhea et al., 2004).

2.2.5 Anthropometric Characteristics

Based on the literature, the average firefighter is approximately 33 years of age, 179 cm tall, weighs 84.5 kg, and has 18.8% body fat. These findings are similar to the physical characteristics of the average Montreal firefighter in the 30-39 year-old category as described by Horowitz and Montgomery (1993). Table 2-

6 provides an overview of the physical characteristics of incumbent firefighters from various sources.

Table 2-6. Body dimension characteristics of firefighters.

Reference	Age (yr)	Height (cm)	Weight (kg)	Fat (%)
Lemon and Hermiston, 1977a	35.0	178.1	83.9	19.2
Byrd and Collins, 1980	34.6	182.0	83.8	20.7
Davis et al., 1982	33.1	176.7	83.4	21.1
Sothmann et al., 1990	35.0	178.0	85.0	N/A
Gledhill and Jamnik, 1992	30.4	179.3	81.6	N/A
Sothmann et al., 1992	32.0	177.0	89.0	19.0
Deakin et al., 1996	30.7	181.2	85.7	N/A
Williford et al., 1999	31.7	177.3	83.9	13.8

2.3 Review of Bona Fide Occupational Requirements

The Canadian government requires that a physical fitness test used to select individuals for firefighting work must meet legislative guidelines (Government of Canada, 1988). It is therefore imperative that scientists work in accordance with the tenants of this legislation when developing fitness assessment standards. This portion of the literature review will provide excerpts from the government policies with specific reference to firefighting. This section of the literature review provides a context for the development of fitness tests and standards.

2.3.1 Canadian Human Rights Act

The purpose of the Canadian Human Rights Act is as follows:

> ... to extend the laws in Canada to give effect, within the purview of matters coming within the legislative authority of Parliament, to the principle that all individuals should have an opportunity equal with other individuals to make for themselves the lives that they are able and wish to have and to have their needs accommodated, consistent with their duties and obligations as members of society, without being hindered in or prevented from doing so by discriminatory practices based on race, national or ethnic origin, colour, religion, age, sex, sexual orientation, marital status, family status, disability or conviction for an offence for which a pardon has been granted.
>
> (Government of Canada, 1988)

In short, the act is intended to prevent discriminatory policies and practices, in this case, in matters related to employment. However, the act does provide an exception. This exception states that it is not a discriminatory practice if, any refusal, exclusion, expulsion, suspension, limitation, specification or preference in relation to any employment is established by an employer to be based on a bona fide occupational requirement (Government of Canada, 1988). Furthermore, there are specific policies describing the criteria, which are to be applied consistently to the facts of each particular case.

2.3.2 Nature of a BFOR

"A bona fide occupational requirement is a condition of employment which is imposed in the sincere belief that it is reasonably necessary for safe, efficient, and reliable performance of the job and which is, objectively, reasonably necessary for such performance." There are three key issues in determining if a BFOR exists:

1. determine the essential components of the job;
2. determine the capacities necessary for safe, efficient and reliable performance of the essential components;
3. assess whether the individual has the capacities determined to be necessary for safe, efficient and reliable performance.

In addition to the three key issues, two criteria must always be considered:

1. the requirement must be objectively necessary;
2. the requirement must be reasonably necessary, so that varying or modifying it would cause undue hardship.

A bona fide occupational requirement must rest upon objective basis. Such objective basis must take into account:

1. existing scientific data, empirical data or expert opinion;
2. the detailed nature of the duties to be performed;
3. the conditions existing in the work place;
4. the effect of such conditions on employees, particularly on those belonging to a category of persons protected against discrimination by the Act.

Although an employer is not required to immediately take measures to obtain valid scientific data, empirical data, or expert opinions; there is a duty to obtain valid expert opinion, scientific- or empirical-data over time.

2.3.3 Essential Components of the Job

Bona fide occupational requirements must relate to the essential components of the job. First, the fitness components and the tests that are selected to assess these attributes must reflect essential components of the job. These essential components may be in the form of “common” or “critical” tasks (Gledhill and Jamnik, 1992a). It is assumed that “common” tasks would be encountered on a regular basis in the course of normal duties. In fire suppression work, climbing ladders or deploying hose might be good examples of common tasks. With respect to “critical” tasks, these may be encountered rarely on the job, however it is understood that employees must be in a state of readiness to perform such work. In fire suppression work, victim rescue is rare, but is considered a critical task.

When designing tests, the procedures and protocols should reflect the manner in which these tasks are performed on the job (Gledhill et al., 2001). For example, in a hose deployment simulation, the type of hose, the length of hose and the surface should be consistent with normal work conditions. The person being tested should also be burdened with the same type of clothing and protective equipment as during fire suppression work. Finally, if the task is normally done under “emergency” conditions at a fire scene, then it may be legitimate to require that the task be done as quickly as possible during the test. Normally, activities done in teams should not be done on an individual basis during testing. Activities that are normally not part of an emergency response (e.g., clean-up) should not be included in "job-related performance" tests.

2.3.4 Risk to Others

A requirement based on considerations of risk to others is legitimate when the absence of the requirement would likely result in injury to the public or to the employee's co-workers. In the context of physical ability, this statement requires that an individual firefighter have the physical capacity to perform their part of the job so as to reduce the risk of injury to the public or another firefighter. For example, an individual firefighter must be physically able to perform a victim or partner rescue at all times.

2.3.5 Day-to-Day Reliable Performance

A requirement based on reliability is legitimate only when the circumstances for which reliability is a requirement are reasonably likely to occur on the job. This area is related to the ability to perform the duties that are considered to be performed frequently enough that a firefighter is likely to encounter the physical demands on a regular basis. A well constructed task analysis would confirm these requirements.

2.3.6 Reliable Performance over a Period of Time

A requirement that an individual be capable of reliably performing the job over a period of time is legitimate when the period of time is necessary for the employer to amortize hiring and training costs. In the case of firefighting, recruits must be physically able to perform fire training activities immediately upon hire. Undue hardship may occur if recruits have to first be trained physically, and then trained in the skills of firefighting (Roberts et al., 2002).

2.4 Process for Establishing a Physical Fitness BFOR for Firefighters

2.4.1 Component vs. Task-Simulation Testing (Construct vs. Content Validation)

There are typically two means of assessing an applicant's physical ability to perform firefighting duties; 1) fitness component; and, 2) task-simulation tests (Docherty et al., 1992; Shephard and Bonneau, 2002). Both methods are recognized as valid approaches to the development of a bona fide occupational requirement in Canada and the United States. An examination of the strengths and weaknesses of these methods will be discussed.

Fitness component testing uses common tests such as step-tests, push-ups and sit-and-reach to measure physical parameters (constructs) considered essential to the performance of firefighting work. Several constructs, including aerobic capacity, muscular strength and endurance, and flexibility have been cited as important for firefighting (Davis et al., 1977; Davis and Dotson, 1987a, 1987b; Davis et al., 1977). Once the constructs have been identified, tests to measure these constructs are then utilized.

In 1982, a classic content validation study of firefighting was performed by Davis et al. (1982). The authors used a series of firefighting tasks selected by a committee of subject matter experts as well as task analysis information. The chosen tasks were a ladder extension, standpipe carry, hose pull, simulated rescue, and simulated forcible entry. Each of the tasks was performed one right after another in a circuit format in full turnout gear and breathing from SCBA. In addition to the job-simulation tasks a series of laboratory measures were taken (anthropometry; body composition; resting heart rate and blood pressure; grip strength; sit-ups; chin-ups; standing long jump; push-ups; sit and reach; cardio-respiratory measures from a treadmill VO_2max test).

Upon completion of the data acquisition, a series of statistical procedures were utilized to determine which factors (laboratory-type tests) best explained performance on the firefighter task circuit, which identified two factors (physical work capacity and resistance to fatigue) made up of nine variables (physical work capacity - grip strength, sit-ups, standing long jump, O_2 pulse, maximum heart rate; resistance to fatigue – percent fat, lean body weight, and final treadmill grade) that best explained the performance of the firefighters on the circuit. The physical work capacity equation had an $r^2=0.90$, while the resistance to fatigue equation produced an $r^2=0.80$. In conjunction these two equations were used to develop a means by which to classify firefighters' physical ability to perform on a task-simulation circuit.

On the other hand job-simulation tests have been developed to assess the fitness for duty of firefighters. This type of testing typically involves the development of test protocols that simulate an essential and frequently encountered job task. Gledhill and Jamnik (1992b) provided one of the best examples of this process. Upon completion of an extensive task-analysis, Gledhill and Jamnik (1992b) developed a series of standardized tests, which replicated actual job tasks that were considered to be the most physically demanding. After developing the testing protocol a group of incumbent firefighters performed each of the tests and then responded to a validation questionnaire as to the similarity of the test to the on-the-job tasks. A scale from 1 to 7 (1 being strongly agree and 7 being strongly disagree) was used. The average rating for the first component (similarity to the on-the-job task) was 1.4/7 to 2.5/7, while the second component (physical demands related to the on-the-job task) was 1.5/7 to 2.4/7. The results of the questionnaire indicated the validity of the job-related tests.

Job-simulation testing can be performed either as discrete tests with rest periods between the activities (Gledhill and Jamnik, 1992b) or in a circuit where there is little or no rest period (Louhevaara et al., 1994). There is some debate as to the best method of testing. The circuit-style of testing provides a more realistic representation of what occurs at a fire scene. However, circuits typically require practice to address pacing issues. Deakin et al (1996) examined the effect of practice on circuit performance time in previously naïve subjects. They found that it took seven practice sessions on the circuit before performance times plateau. In the selection process this could be an expensive and inefficient problem.

On the other hand, using discrete job-related tests may not account for the physical ability of a recruit to perform a series of job-related tasks similar to that encountered under emergency conditions.

2.4.2 Screening vs. Selection Procedures

As described earlier, one aspect of a BFOR is its ability to distinguish between those applicants who physically can and cannot do the job. Many researchers (Brownlie et al., 1985; Considine et al., 1976; Sothmann et al., 1990) have used physical fitness testing as a screening tool, which typically means a pass/fail criteria. Usually, the applicants that pass the physical fitness test move on to the subsequent screening item, without regard to level of performance. Depending on the process used by the hiring department, this method may become cost-prohibitive if there are a large number of applicants. Brownlie et al. (1985) used a series of physical tests with pass/fail criteria, starting with simple “gross physical elimination” procedures to more sophisticated selection criteria that proved a more cost-effective way of selecting applicants.

Others believe that not only should there be pass/fail criteria, but also a means of selecting the “best” applicant by rank ordering or rating the applicants’ performance on the physical fitness tests. Gledhill and Jamnik (1992b) provided criteria for pass/fail criteria on a series of laboratory and job-related fitness tests. As well, they provided a graded scale with which to numerically rank order applicants. They also provided information with regard to “overall” scoring of applicants on the different test items.

As a part of the hiring process Gerkin (1995) stated that

> “…a candidate meeting a designated minimum score on this type of test is presumed physically capable of performing as a firefighter. Ranking the candidates based on this type of test or on any test can be justified only if a correlation exists between performance on the test and performance on the job. If achieving a better score on the physical ability test implies that

> the applicant will be a better firefighter, rank ordering can be used in this portion of the hiring process." (page 874).

2.4.3 Applicant vs. Incumbent Testing

Gerkin (1995) stated that the minimum performance scores for return to duty and periodic evaluation of incumbents should be the same as that used during the hiring process. Although the physical requirements need to be the same the manner in which the firefighters are tested do not. For example, tests that use a "circuit" format has the issue of pacing (Deakin et al., 1996). However, if there are ways of separating the "circuit" format into discrete tests of the same physical demand, then the applicant and incumbent test would be the "same". Some incumbent test protocols have firefighters use a SCBA while performing the activities (Louhevaara et al., 1994; Deakin et al., 1996). The SCBA involves a "learning effect"; firefighters are taught effective breathing techniques for the SCBA. Unless effective breathing and practice time with the SCBA is provided, applicants would be subject to an unreasonable challenge. Both of these parameters are inappropriate for applicant testing and thus, the same method of testing for applicants and incumbents may not be reasonable.

There is research indicating that a firefighters' aerobic capacity declines with age (Horowitz and Montgomery, 1993; Saupe et al., 1991; Sothmann et al., 1990; Sothmann et al., 1992), without a subsequent decline in the physical demands of firefighting work (Lusa et al., 1994). Lusa et al. (1994) surveyed 156 professional firefighters (age range, 22 to 54 years) as to the physical demands of firefighting and the frequency with which they performed the different tasks. Of the respondents, 83% to 88% had performed smoke-diving, which was considered to be the most aerobically demanding, on average four times per year. Rating and/or frequency of the tasks were not significantly affected by age, indicating that the work demands remain constant throughout a firefighter's career.

Shephard (1991) specifically addressed the concept of aerobic capacity declining with age and suggested that one method to combat the decline is to base a minimum aerobic standard “so that the average 45-year-old employee is working at 80% of an acceptable loading.” (page, 99 Shephard, 1987). However, as described by Gledhill and Jamnik (1992a) and Lusa et al. (1994) one cannot change the demands of the job to meet this measure. Therefore a standard must be set to meet the demands of the job as well as provide a buffer to offset the effects of the normal aging process.

2.5 Setting Cut Scores for Firefighter Physical Fitness Tests

Defining the score for a physical fitness test is the final stage in the development of a bona fide occupational requirement (Jackson, 1994). There is no single agreed upon way of determining a cut score in the literature. However, several methods have been employed in the development of a cut score specific to firefighter physical fitness testing.

2.5.1 Mean and Standard Deviation Method

This method uses the performance results of incumbent personnel (firefighters) who are successfully filling their job requirements (Shephard, 1991). Incumbents perform a series of tests from which descriptive statistics (i.e., mean and standard deviation) of the performance scores are determined. These results are then used as the basis of developing the cut off score. An example in the literature is the study by Gledhill and Jamnik (1992b). They utilized the results of 53 incumbent firefighters who performed a series of task-simulation tests. The results were analyzed and a cutoff score was based on the mean performance of the incumbents plus two standard deviations. Therefore, if an applicant's was above the cutoff value, they would be considered a failure. In addition, a minimum acceptable score was described as the mean performance plus one standard deviation. If an applicant had two or more scores that fell between the minimum acceptable and the cutoff score they too would be considered a failure.

2.5.2 Normative Data

The use of normative fitness data is another means by which cutoff scores have been determined (Shephard, 1991). Typically, this procedure involves the use of established fitness tests, which are age and gender adjusted. Gledhill and Jamnik (1992b) used this method in defining a cutoff score for a set of laboratory-type fitness tests (sit-ups and flexibility). The 60th percentile was considered the minimum value for these tests, however, applicants were not considered a failure if they were below the minimum value on any one item.

2.5.3 Energy Cost Information

Cut scores based on energy cost information is a method widely used in the determination of the physical fitness of firefighter applicants. Gathering oxygen cost information from actual and/or simulated firefighting operations is the first step in this process.

Based on an extensive task analysis and oxygen cost analysis, Gledhill and Jamnik (1992a) determined that 90% of the demanding firefighting tasks required a VO_2 of 23 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, while 10% of the tasks required a VO_2 of 41.3 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$. Based on the 'tank life' of an SCBA and the VO_2 values for the fire tasks a minimum VO_2max of 45.0 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ was considered necessary to perform the job safely and effectively with sufficient reserve for unexpected situations.

Another group of researchers (Sothmann et al., 1990) utilized a similar methodology as Gledhill and Jamnik (1992a), for the determination of a minimum VO_2max standard. Sothmann et al. (1990) measured the oxygen cost of incumbent firefighters while performing a task simulation circuit. Subjects were asked to perform the circuit in a manner similar to a fire scene. The mean relative and absolute oxygen consumption during the task simulation was 2.5 $L{\bullet}min^{-1}$ and 30.5 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, respectively. Using this value as the lower limit of VO_2 along with the average work intensity, the authors determined that 33.5 ml•kg^{-1}•min^{-1} represented the minimumVO_2max required to perform the task.

When examining the cut-score methodology, it is apparent that a certain degree of variability exists. This is important to consider, as legal pundits argue for unequivocal standards or cut-scores; for example, dragging a hose 30 m in less than 28 sec. Legislation dictates that standards should be the same for all without consideration for variability. In contrast scientific inquiry utilizes balances of probability to determine an outcome. For example, a probability value of 0.05 indicates that 95 times out of 100 an outcome will occur due to a specific reason and not due to chance (Fletcher et al., 1988). In addition, human performance is composed of a blend of metabolic, cardiovascular, and strength parameters making unequivocal statements about physiological performance difficult. Because of these differing philosophies, this will remain an ongoing issue for scientist working in the area of occupational physiology.

2.6 Summary

It is widely recognized that firefighting is a very physically demanding occupation. Consequently, the need for high levels of physical fitness and the utilization of physical fitness tests to screen and select applicants is generally well accepted in practice. A number of investigators have attempted to document the oxygen cost (or aerobic demands) of fire suppression work. A variety of different methodologies have resulted in remarkably similar average values for oxygen uptake during simulations of firefighting. There are however some potential flaws in not accounting for the effects of the breathing resistance from the SCBA and the weight of protective equipment. Further research is needed to adequately document the aerobic demands of firefighting. Any standard for the aerobic demand should be established after careful consideration of 1) the oxygen cost of fire suppression work, 2) the effects of the SCBA 3) the effects of standard protective equipment and clothing, and 4) the effect of gender. The Canadian Human Rights Act and associated policies provide a framework for interpretation of the bona fide occupational requirements for firefighting. Any new testing program for firefighters should be indisputably linked to the existing physical fitness test and standard for incumbents.

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CHAPTER 3

Heart Rate Responses to Firefighter Training

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3.1 Introduction

Firefighting is a physically strenuous occupation that imposes a high demand on the cardiovascular system. For more than 30 years myocardial infarction has been the leading cause of death among on-duty fire fighters (Barnard, 1979; Washburn et al., 1998). Between 1993 and 1997 MI accounted for 34 to 51% of all firefighter deaths (Washburn et al., 1998). In comparison to other occupations, the epidemiological evidence strongly suggests an increased risk of death from heart disease among firefighters (Choi, 2000). This is of particular interest since firefighters typically undergo stringent health screening protocols prior to selection (NFPA, 2003). Research has shown that the average heart rate response to fire suppression activities ranges from 146 to 195 beats•min^{-1} (Barnard and Duncan, 1975; Sothmann et al., 1992). Due in part to the high cardiovascular strain associated with firefighting, pre-employment medical and/or fitness screening is common (Brownlie et al., 1985; Gledhill and Jamnik, 1992a, 1992b). However, prior to full-time employment in the fire service, many jurisdictions require firefighter certification as a condition of application (Roberts et al., 2002).

Firefighter training usually includes a combination of theory and practical components, typically involving a variety of controlled firefighting activities under emergency-like conditions (AFTS, 2002a). These activities are often completed in two forms:

1. Individual tasks, where the student performs repetitions of a closed fire suppression or rescue skill; or,

2. Scenarios, where groups of students are required to determine suppression or rescue strategy and then perform the necessary tasks.

A number of investigations (Lusa et al., 1993; Romet and Frim, 1987; Smith et al., 2001; Smith and Petruzzello, 1998) have examined heart rate responses to firefighter training, with average responses ranging from 150 to 183 beats•min^{-1}. However, previous research has studied either a single element of fire suppression work, or a scenario contrived by the investigators. While these approaches have provided information, there has yet to be an investigation that has unobtrusively (not directed by the investigation team) examined the heart rate responses of students performing firefighter-training scenarios. In addition, there have been no published studies that have examined other aspects of firefighter training, such as vehicle extrication or the handling of hazardous materials.

Therefore, the purpose of this research project was to systematically and unobtrusively document the heart rate responses of students performing selected physically demanding fire training courses, which could assist in the development of health and fitness screening for fire training.

3.2 Methods

This study was divided into two stages. The first stage involved the identification of firefighter training courses possessing a physically demanding component. In order to characterize the physical demands of firefighter training, the second stage involved the measurement of selected physiological and psychophysical responses during specific training exercises. All volunteers provided written informed consent for participation in the research project that had previously been approved by the institutional ethics review board.

3.2.1 Stage One

Stage I involved extensive discussion with senior fire training instructors and administrators (subject mater experts, SME) to identify those courses which included a physically demanding component. It was agreed that the National Fire Protection Association (NFPA) 1001 Program would be studied for two reasons:

1. It is internationally recognized as the standard in firefighter training (AFTS, 2002a);
2. It encompasses the course material typically required for entry into the firefighting field (AFTS, 2000b).

At the fire training school, the NFPA 1001 program was an 11-week course comprised of theoretical and practical components. Each week focused on a different aspect of firefighter training. The practical sections were typically structured such that the applied components were performed during the middle of the week (Tuesday to Thursday) followed by a written examination on the Friday.

Five courses were identified by the SME as physically demanding: Part I Firefighter (introduction to firefighting); Part IV Firefighter (structural firefighting); Part VI Firefighter (industrial firefighting); Vehicle Extrication (VE); and, Dangerous Goods (DG) (AFTS, 2002b).

In order to further identify the most physically demanding elements within the practical based courses, a questionnaire was used to debrief students who were completing these classes. The students anonymously responded to five open-ended questions on their last day of training in the specific course.

The responses to each question were summarized and grouped into categories. Analysis of the responses revealed the specific elements of each course that were the most physically demanding, which were subsequently studied in this investigation.

3.2.2 Stage Two

This stage involved the monitoring of students performing the physically demanding scenarios identified in Stage I. All of the activities monitored were performed according to the NFPA 1001 program standard. The 16 volunteers in the research project received the same training experience as other students who did not volunteer.

3.2.3 Subjects

According to SME opinion, the subjects in this investigation were representative of typical students in firefighter training (mean ± SD; age = 28.7 ± 7.4 yr, height = 176.9 ± 7.54 cm, weight = 77.9 ± 9.7 kg, and years of volunteer firefighter service = 1.4 ± 2.0 yr).

3.2.4 Protective Equipment

Participants were dressed in duty coat, bunker pants, boots, helmet, anti flash hood, gloves, and a Scott 2.2 (Scott Health and Safety, Monroe, NC, USA) or MSA 2.2 (Mine Safety Appliances Company, Pittsburgh, PA, USA) self-contained breathing apparatus (SCBA), unless otherwise noted.

3.2.5 Firefighter Training Scenarios

The scenarios studied included the most physically demanding tasks that had been previously identified by other students and the SME panel. All scenarios were monitored by the investigators who recorded start and end times (e.g., when the call was initiated and when the instructor ended the scenario). The scenarios studied in this investigation are briefly described below:

- Introduction to Firefighting – Students donned their SCBA and performed a series of activities, such as walking, jogging, crawling, push-ups, and carrying hose until the SCBA safety alarm sounded. Students then breathed-down their SCBA until it was empty, at which time they removed their SCBA mask and the event was ended.
- Structural Firefighting – A variety of scenarios involving simulated structural fires were performed. Typically the students responded to a "call" from the fire station, assessed the situation, set up equipment, entered the building, and suppressed the fire(s). Students also searched for and rescued victim(s). The students performed each scenario as if it

were an emergency situation. Positions included hose line attack, backup, ventilation, and pump operator.

- Industrial Firefighting – The scenarios in this course involved industrial fire suppression activities. Typically students were on scene, assessed the situation, set up equipment, and suppressed the fire(s). The students performed each scenario as if it were a "real" emergency situation. Positions included hose line attack and backup.
- Dangerous Goods – These scenarios involved actions related to the handling of dangerous goods, including searching for dangerous goods, quarantining the exposed area, cleaning up material, and decontaminating the participants. Students responded to a "call" from the fire station, assessed the situation and took appropriate action. The students performed their duties in various configurations of chemical protective ensembles, along with the SCBA.
- Vehicle Extrication – Activities simulated the rescue of passengers from automobile accidents. Students arrived on scene, set up the extrication equipment, determined the appropriate course of action and then proceeded with the extrication. During these scenarios students did not wear the SCBA.

Due to logistical reasons (e.g., student groupings) and to avoid multiple recordings from the same student, only one data record for each individual subject was utilized in the calculations for the various activities. Furthermore, all of the subject records were pooled regardless of the assigned position.

3.2.6 Physiological Measurements

During each of the scenarios, heart rate was continuously monitored using a Polar telemetry system (Vantage NV, Polar USA Inc., CT, USA). The system was programmed to record the average heart rate during 15 second intervals throughout the period of interest. A Polar Advantage computer interface operating with Polar HR Analysis Software Version 5.04.01 (Polar Electro, OY, Finland) was used to transfer the heart rate data to a personal computer for analysis. Heart rate was expressed in absolute terms (beats•min^{-1}) and as a fraction of age-predicted maximum, which was determined by the equation: 220 – age (Fox and Haskell, 1970; Fox et al., 1971).

3.2.7 Psychophysical Measurements

Upon completion of the scenario, participants were asked to indicate their rating for perceived exertion (RPE). A scale from 6 (very, very light) to 20 (very, very hard) was used (Borg, 1982). Respiratory distress (PRD, Morgan and Raven, 1985) was gauged using a scale ranging from 1 (I am not aware of my breathing) to 7 (I am not getting enough air). Thermal distress (PTD, Eves, 2005) was indicated using a scale ranging from 1 (My body temperature is comfortable) to 9 (The heat is unbearable). The "average" response for each scale, for the whole scenario, was recorded immediately at the end of each training scenario.

Subjects were familiarized with all three scales prior to performing the training activities.

3.2.8 Statistical Analysis

Standard descriptive statistics were calculated for all measured variables. All statistical analysis was performed using StatView for Windows version 5.0.1 (SAS Institute Inc., Carry, NC).

3.3 Results

3.3.1 Heart Rate Responses to Firefighter Training Scenarios

During the Introduction to Firefighting scenario, students maintained an average heart rate of 170 ± 8 beats▪min^{-1} (87 ± 6% of HRmax) for an average of 13:04 min:s (Table 3-1). In one case, heart rate exceeded 100% of the age-predicted maximum heart rate during task completion.

The mean duration of the Structural Firefighting scenario was 43:50 min:s, with a corresponding average heart rate of 140 ± 14 beats▪min^{-1}, which was equivalent to 73% of the age-predicted maximum heart rate for this group (Table 3-1). One participant reached 100% of the age predicted maximum.

The Industrial Firefighting scenario lasted 40:00 min:s, and evoked an average heart rate of 110 ± 9 beats▪min^{-1}, equivalent to 56% of the age-predicted maximum heart rate. However, peak heart rate responses reached as high as 94% of the predicted maximum.

The average heart rate during the Dangerous Goods scenario was 108 ± 16 beats•min^{-1}, equivalent to 55% of the age-predicted maximum heart rate. Although the heart rate responses were low, the duration of the scenarios was quite long (58:42 min:s) in comparison to the other activities studied.

The average heart rate during the Vehicle Extrication scenario was 108 ± 16 beats•min^{-1}, equivalent to 57% of the age-predicted maximum heart rate. The duration of the scenarios averaged 43:00 min:s.

3.3.2 Psychophysical Dimensions

The student's RPE (Table 3-2) mirrored the heart rate responses. The introduction to firefighting scenario was rated as the most physically demanding activity (mean of 14), which corresponded to the descriptor "hard". The Dangerous Goods scenario was perceived to be the least demanding (mean of 10) or "fairly light".

PRD and PTD ratings followed the same pattern as the RPE, with the Introduction to Firefighting eliciting the greatest distress (4 on the 7-point scale – "getting hard to breathe") and the Dangerous Goods scenarios the least (2 on the 7-point scale – "starting to breathe hard") (Table 3-2).

The PTD responses of the students varied considerably among the scenarios. The Introduction to firefighting elicited the highest response with an average descriptor of "I am hot" (5 on the 9-point scale). The students reported that the Industrial Firefighting course was the least distressing (2 on the 9-point scale – "starting to get hot") (Table 3-2).

3.4 Discussion

The purpose of this investigation was to systematically and unobtrusively study the heart rate responses of fire training students without compromising or influencing the training process. This is the first investigation to thoroughly examine a selection of practice-based courses related to basic fire training. The results demonstrated that within certain courses, specific tasks impose a significant stress upon the cardiovascular system. This is an important first step in developing appropriate health and physical fitness screening protocols for students entering into fire training.

3.4.1 Heart Rate Response to Firefighter Training

When all of the data were collapsed, the average heart rate response of the students performing firefighter training was 127 beats•min^{-1} which corresponded to 66% of the predicted maximum. The average heart rate responses for the various courses involved pooling of the subjects data, regardless of the activities they were performing. The activities involved both high and low physical efforts. Since the data was pooled, interpretation of the average heart rate should be made with caution, as this may either under or over estimate the demands of the course. It is therefore important to examine the peak heart rates that were achieved during training. In this case the averaged heart rate response for all of the data set was equal to 164 beats•min^{-1}, or 85% of the predicted maximum. However, there were cases where participant's responses reached and exceeded their predicted maximum heart rate.

The results of the current study were similar in many ways to other firefighting research. Romet and Frim (1987) studied the heart rate responses of a group of professional firefighters performing a series of structural fire scenarios over a two-day period. Each of the subjects executed various position-specific duties (e.g., pump operator, nozzle person), and the average heart rate response in this study was found to be 131 beats•min^{-1}.

In the current study, heart rates rose from rest by 19 to 52 beats•min^{-1} depending upon the course and activity being performed. This is comparable to heart rate responses obtained during training (Romet and Frim, 1987) and actual firefighting (Barnard and Duncan, 1975) in other studies. During actual firefighting emergencies, Sothmann et al. (1992) reported heart rate responses of 157 beats•min^{-1}, or 88% of maximal heart rate. It is apparent that the heart rate responses of the subjects in the current study are consistent with those observed in firefighter training and actual firefighting.

3.4.2 Duration and Frequency of Training Scenarios

During a typical training day each student participated in approximately four to six scenarios. Scenario duration ranged from 10:54 to 74:00 min:s. During the training scenarios, students would typically cycle through various positions or perform several different tasks, or repeated efforts at the same task, per evolution. Thus, students would be exposed to differing levels of physical stress within a scenario or between different scenarios. Although this type of situation is not common in the "real world" of firefighting, training is done in this way for two reasons. Firstly, repetition is often required for mastery of specific skills. Secondly, firefighting normally involves teamwork, and multiple repetitions of training scenarios allow students to experience different aspects of the team approach to fire suppression. As described in the literature, the average duration of actual fire suppression duties is approximately 15 minutes (Sothmann et al., 1990; Sothmann et al., 1992), out of 52 minutes at a fire scene (Austin et al., 2001) and 1 call per every 10 days (Austin et al., 2001). Consequently, the volume of physical stress encountered during firefighter training exceeds the physical stress that is normally encountered by career firefighters.

3.4.3 Psychophysical Responses

The perception of effort responses in the current investigation were lower than those reported in another study (Smith et al., 2001). However, this is most likely due to differences in study design. The other investigation requested that subjects perform activities as quickly as possible, instead of at the "safe and effective" pace as enforced by the instructors in this investigation.

3.4.4 Screening for Firefighter Training

Considering the physical demands of firefighting and the public's expectation of protection, it is common for jurisdictions to set physical fitness requirements for applicants (Davis et al., 1982; Gledhill and Jamnik, 1992a, 1992b) and, in some cases, incumbents (Deakin et al., 1996; Louhevaara et al., 1994). Typically, a series of laboratory and/or job-related tests of health (NFPA,

1582) and fitness (Davis et al., 1982; Deakin et al., 1996; Gledhill and Jamnik, 1992a, 1992b; Louhevaara et al., 1994) are administered in order to assess an individual's capacity to safely and effectively manage the stress of firefighting work. To date, there have been no published criteria used to screen firefighter-training applicants. This is partly due to a lack of scientific documentation of the physical and physiological responses to fire training. Based on the results of this study, it was recommended that a medical screening protocol be developed to appropriately determine which individuals are able to safely and effectively undertake physically demanding fire training courses. In addition to being medically fit to undergo fire training, students should also be physically able to perform the various tasks.

3.4.5 Conclusion

The findings of this study demonstrate that the practical components of firefighter training are very similar to those of actual firefighting in terms of heart rate response and perceived effort. However, the daily volume of stress is typically much greater than that encountered in actual firefighting. The cardiac strain exhibited by the students during the various training scenarios underscores the importance of medically screening students/recruits wishing to undertake such training. In addition, due to the similarity of physical demands among training and actual firefighting, it may be reasonable to employ similar fitness assessment standards.

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Table 3-1. Heart rate responses (mean ± SD and range) of students during firefighter-training (*n*=16).

Course	Duration (min:s)	Average HR (beats•min^{-1})	% of HRmax	Peak HR (beats•min^{-1})	% of HRmax
Introduction	13:04 ± 2:04	170 ± 8	87 ± 6	191 ± 8	98 ± 6
	(10:54 - 16:05)	(161 - 185)	(80 - 98)	(184 - 205)	(92 - 109)
Structural	43:50 ± 9:35	140 ± 14	73 ± 9	175 ± 15	91 ± 8
	(35:00 - 63:00)	(120 - 160)	(60 - 85)	(157 - 189)	(79 - 100)
Industrial*	40:00 ± 0:00	110 ± 9	56 ± 6	154 ± 22	79 ± 11
	(NA)	(101 - 121)	(50 - 64)	(133-186)	(68 - 94)
DG	58:42 ± 12:38	108 ± 16	55 ± 10	150 ± 23	77 ± 13
	(43:35 - 74:00)	(77 - 122)	(39 - 66)	(109 - 168)	(55 - 93)
VE	43:00 ± 10:03	108 ± 16	57 ± 7	150 ± 22	79 ± 11
	(35:00 - 55:00)	(89 - 143)	(51 - 73)	(129 - 189)	(67 - 97)

*only one trial was obtained for the industrial course. DG = dangerous goods; VE = vehicle extrication

Table 3-2. Psychophysical responses (mean ± SD) to selected firefighter-training scenarios (*n*=16).

Course	RPE	PRD	PTD
Introduction	14 ± 2	4 ± 1	5 ± 1
Structural	12 ± 3	3 ± 1	3 ± 2
Industrial	12 ± 2	2 ± 1	2 ± 1
Dangerous Goods	10 ± 2	2 ± 1	2 ± 1
Vehicle Extrication	12 ± 1	2 ± 1	4 ± 1

RPE = Rating of perceived exertion, PRD = perceived respiratory distress, PTD = perceived thermal distress.

CHAPTER 4

Effects of the Self-Contained Breathing Apparatus and Fire Protective Clothing on Maximal Oxygen Uptake

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4.1 Introduction

Firefighting is considered to be one of the most physically demanding and hazardous civilian occupations (Gledhill and Jamnik, 1992a, 1992b; Guidotti and Clough, 1992). Lusa et al. (1994) determined that regardless of age or rank, one of the most physically demanding tasks faced by firefighters is that of smoke-diving (search and rescue). This task typically involves entry into a dark, smoke-filled structure where the firefighter must search, by feel, for casualties and then evacuate them to safety. Research has shown that search and rescue work during actual fire emergencies elicits near-maximal heart rate responses (Sothmann et al., 1992) and places a significant demand on aerobic metabolism (Gledhill and Jamnik 1992a; Bilzon et al., 2001)

Environmental hazards require that firefighters wear personal protective equipment (PPE) and a self-contained breathing apparatus (SCBA). Although there have been improvements in ergonomic design and reduced weight, there is still evidence to suggest that the protective clothing and respiratory devices used by firefighters negatively affect maximal oxygen consumption (VO_{2max}) (O'Connell et al.,1986; White et al., 1991; Eves et al., 2005).

Maximum oxygen consumption is often measured to ensure that firefighters are physically capable of performing their duties safely and effectively (Gledhill and Jamnik, 1992b; Sothmann et al., 1992). However, VO_{2max} tests are typically performed on a treadmill or cycle ergometer, with the individual dressed in normal exercise clothing (e.g., shorts, t-shirt and running shoes), while breathing through a low-resistance valve, which is not consistent with the PPE required at work (Kilbom, 1980; Louhevaara et al., 1985; Gledhill and Jamnik, 1992b).

Previous investigations have assessed either the effect of the SCBA (Eves et al., 2005) or PPE (Louhevaara et al., 1995) on VO_{2max}; however none have examined the combined effects. Since firefighters are required to work in PPE and wear the SCBA, logically, aerobic fitness should also be evaluated in this condition. The purpose of this study was to investigate the combined effects of fire protective clothing and the SCBA on maximal oxygen consumption.

4.2 Methods

4.2.1 Participants

Twelve healthy males, who were very familiar with exercise in firefighting ensemble and breathing apparatus, served as participants in this investigation. The physical characteristics of the participants were (mean ± SD): age 31.0 ± 9.1 years; stature 179.8 ± 6.4 cm; mass 83.0 ± 7.1 kg; mass in PPE 104.3 ± 7.28 kg. Volunteers provided written informed consent for participation in the project that had previously been approved by the appropriate institutional ethics review board.

4.2.2 Experimental Design

Each participant performed two graded exercise tests (GXT) to determine maximal oxygen consumption. In one condition, participants were dressed in firefighting personal protective ensemble while breathing through the SCBA

(GXT_{PPE}). In the second condition, participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT_{PT}). Each test was separated by at least 24 hours during which participants were asked to refrain from strenuous exercise. The order of the tests was randomized.

4.2.3 Exercise Test Protocol

All tests were carried out at normal room temperature (21-24 °C). The exercise protocol was performed on a motor driven treadmill (Model 18237-2-6-95; Standard Industries, Fargo, ND). The same loading protocol was used for both tests. Each participant initially walked at a constant speed (93.8 $m \cdot min^{-1}$) while grade increased by 2% every two minutes until 10% grade was reached. Subsequently, grade was increased by 2% every minute until 20% grade was reached. If the subject was able to continue, combinations of grade (2% increments) and/or speed (13.4 $m \cdot min^{-1}$ increments) increases were individually selected in order to elicit volitional exhaustion. The highest 20 second VO_2 reading was accepted as VO_{2max} if at least two of the following criteria were met: a plateau in oxygen consumption was observed despite an increase in work rate; a respiratory exchange ratio (RER) >1.10; and/or, a heart rate greater than or equal to age-predicted maximum was reached. Power output at VO_{2max} was calculated using the equation [mass x speed x grade]. The mass used in this calculation was the combined weight of the participant and any clothing and equipment carried during the test (either PT or PPE condition).

4.2.4 Clothing

During the GXT_{PT} condition, participants wore athletic shorts, t-shirt and running shoes. During GXT_{PPE}, a duty coat and bunker pants (System 300 CGSB; SafeCo MFG. Inc., Scarborough, ON), helmet (Model 911; SafeCo MFG. Inc., Scarborough, ON), anti-flash hood (Model: 30176; PGI, Inc., Green Lake, WI) and firefighter gloves (Model: Firefighter, The Glove Corp., Alexandria, IN) were added. Each participant also wore a Scott 4.5 SCBA system (Scott Health and Safety, Monroe, NC) comprising a face piece assembly (AV 2000), regulator (Scott Presur-Pak®, E-Z Flo™), and backpack (harness and a full 60-min Scott Air-Pac® fibre composite air cylinder). The total weight of the equipment and SCBA was 21.4 ± 1.8 kg.

4.2.5 Measurements

Respiratory gas exchange (oxygen consumption [VO_2], carbon dioxide production [VCO_2], respiratory exchange ratio [RER], fraction of expired oxygen [F_EO_2] and carbon dioxide [F_ECO_2]) and ventilatory data (ventilation [V_E], tidal volume [V_T], breathing frequency, inspiratory and expiratory time) were acquired during each GXT with a TrueMax 2400 (ParvoMedics, Salt Lake City, UT) computerized metabolic measurement cart (MMC). The gas analyzers were calibrated immediately prior to each test using gases of known concentration. Calibration of the gas analyzers was checked immediately following each test to verify that calibration had been maintained during the data collection period. The pneumotachometer (Hans Rudolf 3813, Kansas City, MO) was calibrated according to manufacturer specifications using a 3-L syringe (Hans Rudolf 5530 series).

In the GXT_{PT} condition, expired gases were collected via a Hans Rudolf 2700 series low-resistance breathing valve. In order to capture expired gases during the GXT_{PPE}, the SCBA regulator was fitted with a Plexiglas cone that formed an airtight seal over the exhalation ports (for a detailed description see Eves et al., 2002). The distal end of the cone and breathing valve were connected to the MMC via a two-metre long corrugated flexible plastic hose with an inside diameter of 2.8 cm, the same hose was used for the GXT_{PT} condition. Prior to experimental testing, the SCBA regulator was tested by an authorized technician to ensure proper working order.

4.2.6 Statistical Analysis

Respiratory gas exchange data were averaged for each minute during the exercise protocol, except at maximal exercise where the highest 20 s reading was used to detect VO_{2max}. Differences between conditions were analyzed using a one-way repeated measures analysis of variance. Significant *F*-ratios were examined on a *post hoc* basis using the Scheffe′ procedure for multiple comparisons. Pearson Product-Moment correlation coefficients were used to examine the relationships between variables of interest. Descriptive statistics are presented as means and standard deviations. A probability value equal to or less than 0.05 was considered significant.

4.3 Results

All participants completed both test protocols up to and including 18% grade. Figures 4-1, 4-2, 4-4, and 4-5 were drawn to show the physiological responses for all subjects. The "max" data point on these figures represents the mean maximum value for each variable regardless of the workload.

4.3.1. Gas Exchange Responses

The oxygen cost of walking on the treadmill in the GXT_{PPE} condition was significantly greater than the GXT_{PT} condition at all grades up to 18% (Figure 4-1). At peak exercise, oxygen consumption and carbon dioxide production during GXT_{PPE} were significantly lower compared to the GXT_{PT} condition. It should be noted that power output at VO_{2max} was significantly higher in the PT condition than in the PPE condition (353.8 ± 41.3 W vs. 320.9 ± 38.1 W).

At equivalent ventilation rate (the ventilation rate corresponding to VO_{2max} during the GXT_{PPE}), the F_EO_2 was significantly higher while F_ECO_2 was significantly lower during the GXT_{PPE} than the GXT_{PT} condition (Table 4-1). The respiratory exchange ratio and the ventilatory equivalent (V_E/VO_2) were not significantly different between conditions at maximal exercise (Table 4-1).

4.3.2. Ventilatory Responses

Ventilation during GXT_{PPE} was significantly higher during each of the test stages 4% to 18% grade; however, V_E was significantly lower at maximal exercise by 14.3 ± 9.9% (Figure 4-2 and Table 4-1). Correlation analysis was used to examine the relationship between VO_{2max} and V_E at maximal exercise. The reduction in VO_{2max} during the PPE condition was highly related (r=0.81) to the decrease in V_E (Figure 4-3).

Tidal volume and breathing frequency displayed different patterns for both GXT_{PPE} and GXT_{PT} (Figures 4-4 and 4-5). Tidal volume during GXT_{PPE} was significantly higher during the earlier stages of exercise but lower during the later stages and at maximal exercise VT was lower than the GXT_{PT} condition (Figure 4-4 and Table 4-1). Breathing frequency was significantly higher during most of GXT_{PPE} but there was no significant difference at maximal exercise (Figure 4-5). Inspiratory time during the GXT_{PPE} was significantly shorter than GXT_{PT} at maximal exercise, whereas expiratory time was the same (Table 4-1).

4.4 Discussion

The submaximal data presented in this study are comparable with previous research, showing that at equivalent external workloads, VO_2, V_E, and heart rate are higher in PPE conditions versus PT (Davis and Santa Maria, 1975; Louhevaara et al.,1985; O'Connell et al., 1986; White et al., 1991; Lusa et al, 1993). It has been suggested that the increased physiological responses during submaximal exercise in PPE are attributed to a variety of factors. Aspects such as increased weight of the equipment (Louhevaara et al., 1985; Duggan, 1988), a "hobbling effect" (Teitlebaum and Goldman, 1972), or pronounced forward lean (Soule and Goldman, 1977; Gordon et al., 1983) could individually or in combination affect the efficiency of exercise and work tolerance.

The main finding of this investigation was the substantial reduction in VO_{2max} in the PPE condition compared to PT. The 18% reduction is similar to the results of a study by Louhevaara et al. (1986b) where the participants wore only the SCBA facemask, harness and tank (~17%). More recently, Eves et al. (2005) reported similar reductions in VO_{2max} that were explained mainly by the resistance of the SCBA regulator. Louhevaara et al. (1995) reported that VO_{2max} was reduced by 4% (ns) wearing fire protective clothing, which supports that most of the attenuation of VO_{2max} is caused by the breathing apparatus.

The results from the current study indicate that the decrease in maximal V_E during the GXT_{PPE} was the reason for the decreased VO_{2max}. The cause for the decreased V_E while breathing from the SCBA is not clear, but may be related to an increased work of breathing due to expiratory resistance caused by the regulator (Eves et al., 2002) and/or impairment in thoracic excursions due to the weight of the SCBA harness (Louhevaara et al., 1985).

Tidal volume plateaued at approximately 80% of VO_2max during the PPE condition and this corresponded to 83% of maximal V_T during the PT condition (Figure 4-4). Inspiratory time was significantly shorter in the PPE condition, however despite the reduction in tidal volume, expiratory time was not changed. This suggests that more effort was required to exhale against the resistance of the regulator. While maximal breathing frequency was not different in the two conditions, there is clear evidence that when tidal volume reached a plateau in the PPE condition (Figure 4-4), ventilation was maintained by a rapid increase in breathing frequency (Figure 4-5).

The SCBA may cause a change in alveolar ventilation (V_A) during heavy exercise (Donovan and McConnell, 1998), which in turn could contribute to lower arterial saturation (S_aO_2). When the expired fraction of O_2 and CO_2 at similar V_E were compared between test conditions, significantly higher F_EO_2 and lower F_ECO_2 were found in the PPE condition. Eves et al. (2002), using pulse oximetry to estimate S_aO_2, found that during a PPE GXT, a moderate level of exercise-induced hypoxemia occurred, which may be related to an inadequate V_A. These observations suggest the possibility of altered gas exchange during heavy exercise with the SCBA, however for confirmation, further research is required.

The effects of the SCBA and PPE on VO_{2max} have some practical implications regarding the health and safety of firefighters. Several researchers have measured or estimated oxygen consumption during firefighting work (Sothmann et al., 1990; Sothmann et al., 1991; Gledhill and Jamnik, 1992a; Lusa et al., 1993; Bilzon et al., 2001). These results indicate that fire suppression and rescue work typically requires an average VO_2 of approximately 34 $ml•min^{-1}•kg^{-1}$. Based on the understanding of the aerobic demands of fire rescue work, recommendations for minimum VO_{2max} levels for firefighters range from 39 – 45 $ml•min^{-1}•kg^{-1}$ (O'Connell et al., 1986; Gledhill and Jamnik, 1992b; Sothmann et al, 1992; Bilzon et al., 2001; NFPA, 2002), with the mean being approximately 42 $ml•min^{-1}•kg^{-1}$. Typically, the oxygen cost of firefighting has been determined during work simulations while wearing PPE and SCBA. On the other hand, none of the recommendations for VO_{2max} have included guidelines for equipment or clothing configurations during testing.

By way of example, if the mean VO_2 during fire rescue work is assumed to be 34 ml•min^{-1}•kg^{-1}, and the mean recommended VO_{2max} is 42 ml•min^{-1}•kg^{-1}, the aerobic demands of the work represent approximately 80% of VO_{2max}. However, as shown in the present study, the VO_{2max} in PPE and on SCBA is significantly reduced from the level measured in the "traditional" test. Therefore, the firefighter would have to work at a higher fraction of maximal aerobic power. The requirement to work at greater than 80% of VO_{2max} may compromise the reserve for safe and effective performance and total potential work time (Louhevaara et al., 1986b; Ilmarinen, 1992a, b). Consequently, the results of this study need to be considered when evaluating aerobic fitness standards for firefighters.

4.5 Conclusions

It is evident that firefighting protective equipment and especially the SCBA, has a significant negative effect on maximal oxygen consumption. Nearly two decades of equipment design have not alleviated the negative effects of the SCBA on VO_{2max} that have been reported by previous researchers. Therefore, when testing the aerobic fitness of firefighters, the effects of the SCBA and protective clothing on maximal work capacity must be taken into consideration. A logical alternative to the practice of testing aerobic fitness in traditional exercise clothing is to adopt a method of testing similar to that described above. This approach to measuring VO_{2max} should provide a more functional assessment of aerobic work capacity in firefighters.

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Table 4-1. Physiological responses at maximal exercise (mean ± SD).

Variable	GXT_{PT}†	GXT_{PPE}‡
Oxygen consumption (ml•min^{-1}•kg^{-1})	52.4 ± 8.5	43.0 ± 5.7*
Oxygen consumption (L•min^{-1})	4.32 ± 0.6	3.55 ± 0.4*
Carbon dioxide production (L•min^{-1})	5.31 ± 0.7	4.31 ± 0.5*
Fraction of expired oxygen (%)	17.29 ± 0.2	17.43 ± 0.28*
Fraction of expired carbon dioxide (%)	4.32 ± 0.26	4.07 ± 0.26*
Respiratory exchange ratio	1.24 ± 0.1	1.21 ± 0.1
V_E/VO_2	38.4 ± 2.2	39.6 ± 3.5
Pulmonary ventilation (L•min^{-1})	167.1 ± 15.6	142.8 ± 18.0*
Tidal volume (l)	3.17 ± 0.4	2.62 ± 0.4*
Breathing frequency (breaths•min^{-1})	53 ± 7	55 ± 7
Inspiratory time (s)	0.48 ± 0.08	0.34 ± 0.06*
Expiratory time (s)	0.72 ± 0.08	0.75 ± 0.07
Heart rate (beats•min^{-1})	188 ± 6	189 ± 7

GXT = graded exercise test; V_E = ventilation.

*Significant difference between GXT_{PT} and GXT_{PPE} ($p < 0.05$).

† Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT_{PPE}).

‡ Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT_{PT}).

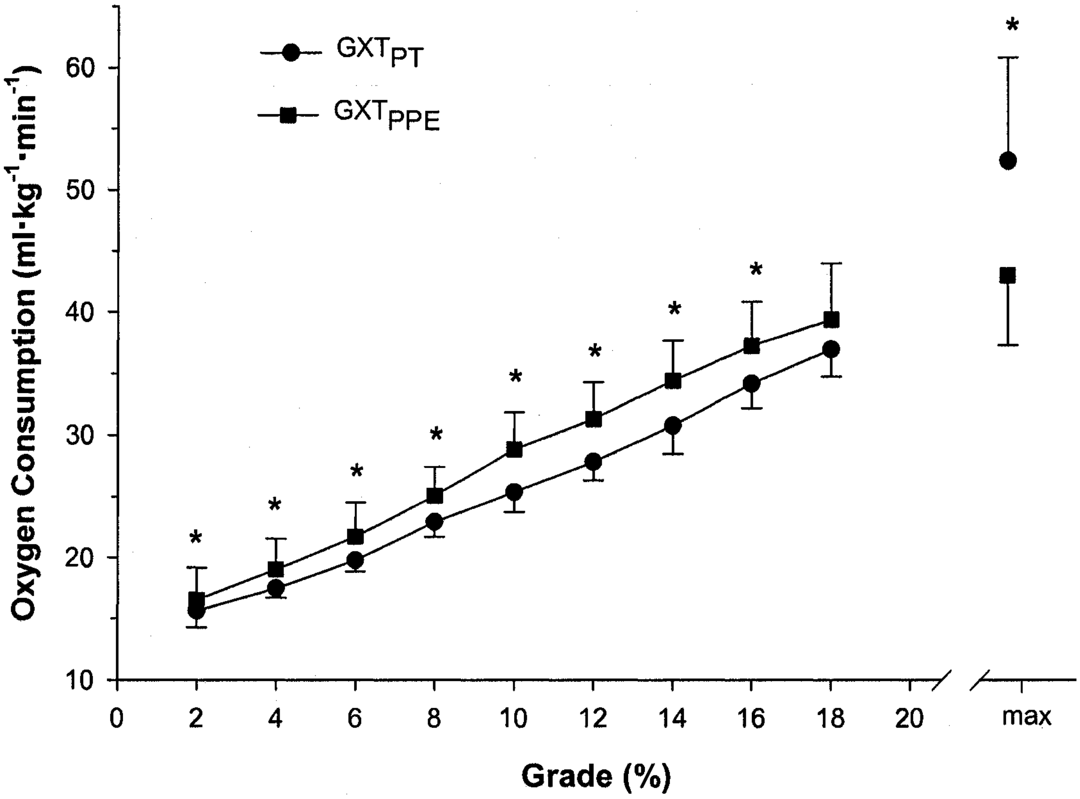

Figure 4-1. Mean (±SD) oxygen consumption during GXT$_{PT}$ and GXT$_{PPE}$. *Significant difference between GXT$_{PT}$ and GXT$_{PPE}$. GXT = graded exercise test. Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT$_{PPE}$). Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT$_{PT}$).

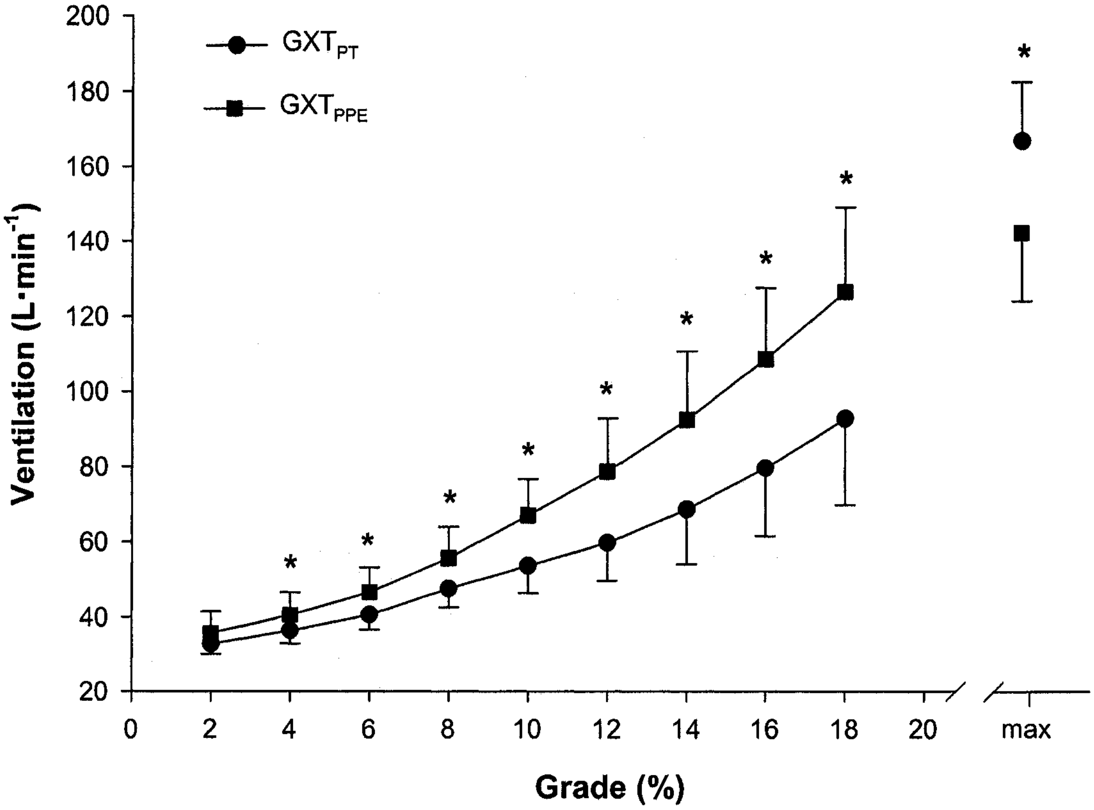

Figure 4-2. Mean (±SD) pulmonary ventilation (V_E) during GXT$_{PT}$ and GXT$_{PPE}$. *Significant difference between GXT$_{PT}$ and GXT$_{PPE}$. GXT = graded exercise test. Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT$_{PPE}$). Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT$_{PT}$).

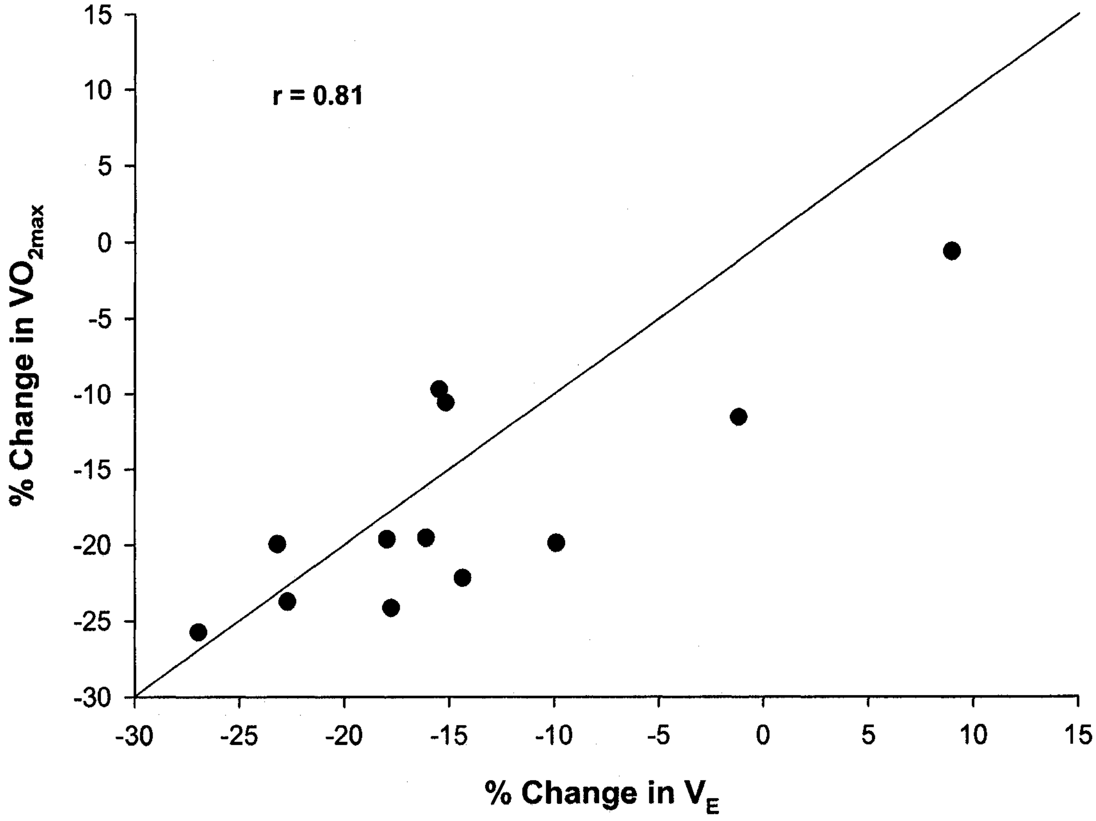

Figure 4-3. Scattergram of the % change in maximal oxygen consumption and peak ventilation (V_E) between GXT_{PT} and GXT_{PPE}. GXT = graded exercise test. Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT_{PPE}). Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT_{PT}).

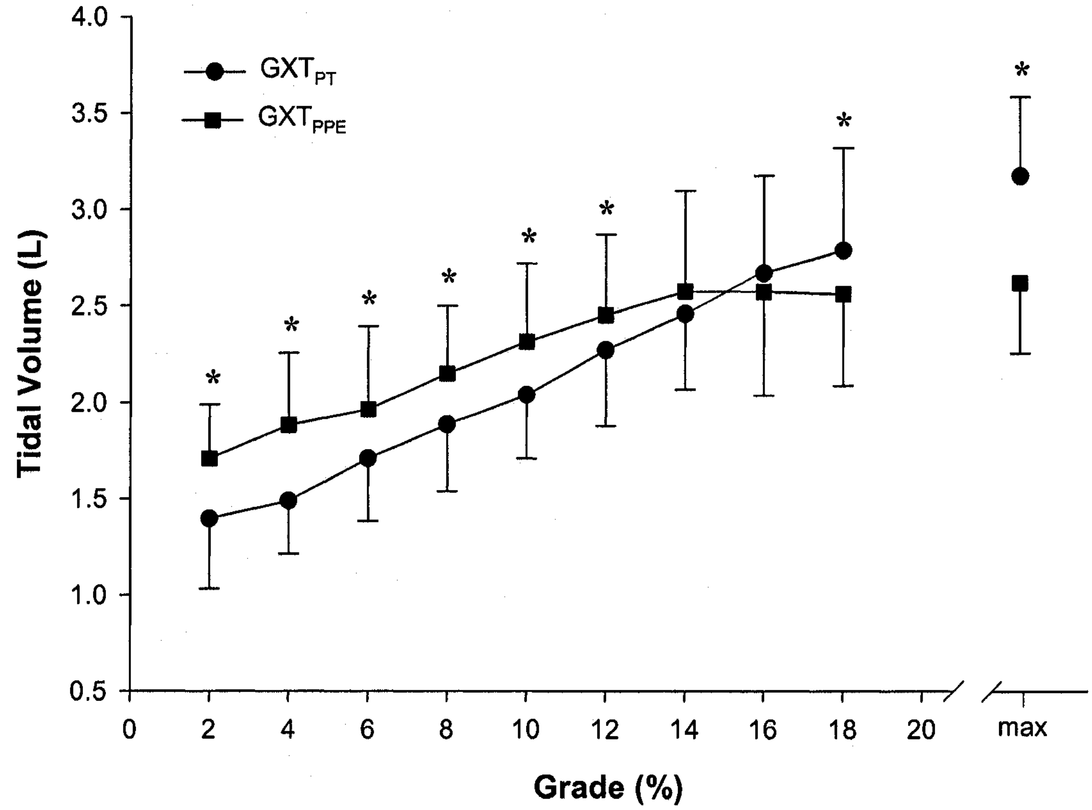

Figure 4-4. Mean (±SD) tidal volume (V_T) during GXT$_{PT}$ and GXT$_{PPE}$. *Significant difference between GXT$_{PT}$ and GXT$_{PPE}$. GXT = graded exercise test. Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT$_{PPE}$). Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT$_{PT}$).

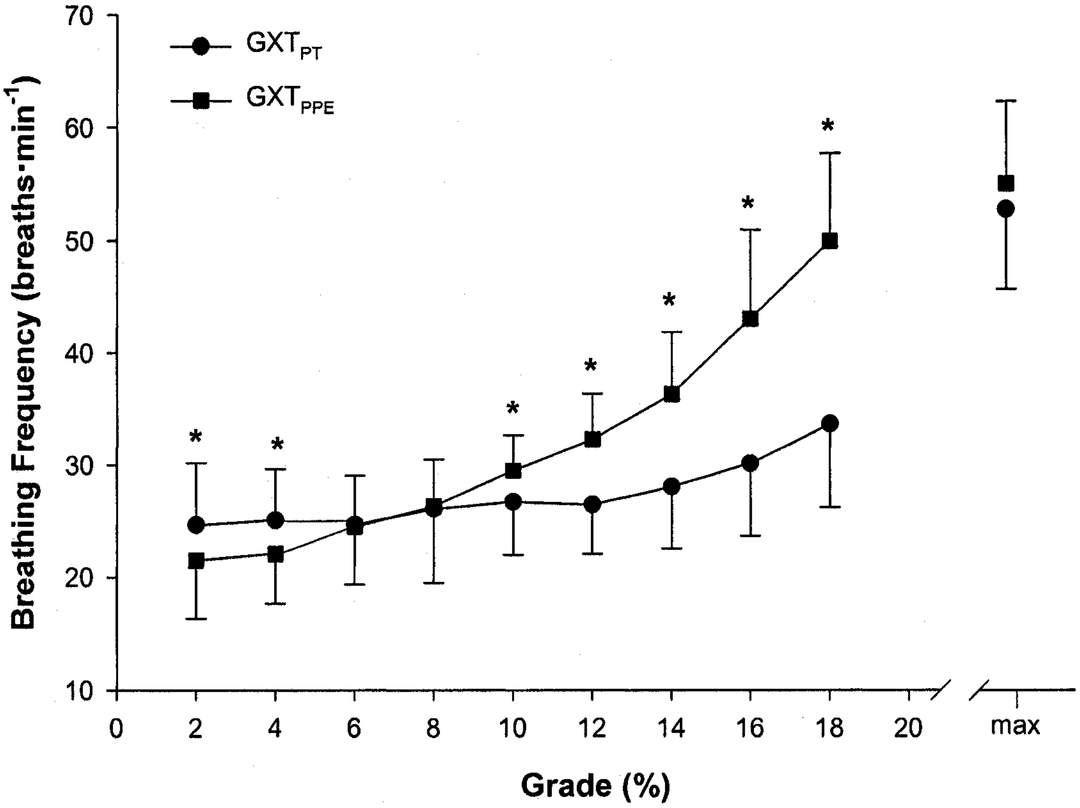

Figure 4-5. Mean (±SD) breathing frequency during GXT_{PT} and GXT_{PPE}. *Significant difference between GXT_{PT} and GXT_{PPE}. GXT = graded exercise test. Participants were dressed in firefighting personal protective ensemble while breathing through the self-contained breathing apparatus (GXT_{PPE}). Participants were dressed in shorts, t-shirt and running shoes, while breathing through a typical low-resistance breathing valve (GXT_{PT}).

CHAPTER 5

Evaluation of the Aerobic Demand of the FF Test and Development of a Treadmill Test for Firefighters

A version of this chapter has been submitted to
Applied Physiology, Nutrition, and Metabolism

5.1 Introduction

There is consensus that firefighting is a physically demanding occupation that requires good cardiovascular fitness. For several decades researchers have studied the aerobic demands of firefighting. This interest arose following the observation that myocardial infarction was the leading cause of death for on-duty firefighters (Bernard and Duncan, 1975; Davis et al., 2002). In 1975, Bernard and Duncan were the first to report that near maximal heart rates were sustained for extended periods during actual firefighting duties. These authors suggested that firefighters with inadequate cardiorespiratory fitness may be at increased risk of myocardial infarction during intense work. In response, a number of investigations were undertaken to determine an acceptable level of cardiorespiratory fitness (i.e., VO_2max) required for a firefighter to work safely and effectively (Davis and Dotson, 1987a; 1987b).

In order to set an aerobic fitness standard for firefighters, determination of the metabolic demands during actual firefighting is required. Direct measurement of oxygen consumption (VO_2) during actual emergencies would, in theory, be the most accurate method, however this was not practical. In the absence of direct measurement, investigators (Sothmann et al., 1992) have estimated oxygen consumption during actual emergencies from heart rate recordings. Others have either estimated or measured the oxygen cost of simulated firefighting activities such as: stair climbing (O'Connell et al., 1986); individual task performance (Lemon and Hermiston, 1977b; Gledhill and Jamnik, 1992a), simulated smoke-diving (Lusa et al., 1994); simulated fire scenarios (Sothmann et al., 1990;

1992b); simulated shipboard firefighting (Bilzon et al., 2001); and simulated rescue scenarios (von Heimburg et al., 2006). The VO_2 values reported from individual studies were somewhat dependent on factors such as the method (direct measurement or estimation), the type of activity (e.g., single activity or a series of activities), pacing (self-paced or investigator determined), environmental factors (e.g., heat and/or smoke) and the duration of the simulation. Although the studies vary in design, the results suggest that fire-rescue operations require an average oxygen consumption of approximately 34 $ml \cdot kg^{-1} \cdot min^{-1}$ (approximate range: 16 to 55 $ml \cdot kg^{-1} \cdot min^{-1}$), irrespective of duration (approximate range: 2 to 17 min).

Various researchers have relied on these data to set aerobic fitness standards for firefighters and recommendations for minimum VO_2max range from 33.5 to 48 $ml \cdot kg^{-1} \cdot min^{-1}$ (Bilzon et al., 2001; Davis and Dotson, 1987a; 1987b; Gledhill and Jamnik, 1992b; Lemon and Hermiston, 1977; Lusa et al., 1993; O'Connell et al., 1986; Sothmann et al., 1990; Sothmann et al., 1991; von Heimberg et al., 2006). Despite the effort devoted to identification of a minimum VO_2max for firefighters, there is a lack of agreement among researchers, which suggests further study is warranted. Furthermore, one might question whether VO_2max is the most appropriate measure of aerobic fitness, since it has been reported that most fire operations take place at submaximal intensity for potentially for prolonged periods (Gledhill and Jamnik, 1992a).

As an alternative to measuring VO_2max, and in part to address the submaximal nature of firefighting operations, simulated firefighting work tests have been developed (Louhevaara et al., 1994; Deakin et al., 1996; IAFF, 1999). Typically, these tests consist of a sequence of job-related tasks that must be completed within a specified time period. This format implies that in order to meet the time standard, an acceptable work-rate that is representative of the energetic demands of the job must be achieved. If the test is a valid reflection of the physiological demands of the job, then the fitness requirements (e.g., aerobic fitness) are indirectly evaluated based on the performance time.

To assess the fitness for duty of Canadian Forces (CF) firefighters, Deakin et al. (1996) developed a simulated firefighting work circuit (FF Test). This 10-item circuit involves a number of firefighting tasks (e.g., dragging charged hose, victim rescue, forcible entry, etc) separated by short walks of 15 or 30 m. The activities in this test are performed continuously with standardized equipment and course dimensions. Successful completion of the FF Test requires that the series of tasks be accomplished in 8 minutes or less. The aerobic demands associated with meeting this performance requirement have not, to our knowledge, been directly measured. Furthermore, it is unclear whether the aerobic demands of meeting the standard are the same for males and females.

Although simulated work tests have attributes that may appeal to some fire departments, there are situations where it may not be appropriate to use such tests. Work simulations involve a certain amount of pacing and skill acquisition, in some cases requiring several practice sessions (Deakin et al., 1996). Practice sessions are time consuming during recruitment competitions, practice can affect cost effectiveness (Brownlie et al., 1985). In addition these types of tests do not allow for the evaluation of discrete fitness attributes. Therefore, it may be necessary to establish a test of aerobic fitness that is specific to the demands of firefighting (submaximal workload) that is absent of practice and skill acquisition.

The main purpose of this study was to directly measure the aerobic demand of the FF Test, with particular emphasis on documenting the average oxygen cost associated with the 8-minute performance standard. A second purpose was to describe the responses of selected cardiorespiratory variables when subjects completed the FF Test as quickly as possible. The third objective was to investigate the efficacy of constant workload treadmill test to assess firefighter aerobic fitness. The fourth objective was to examine the responses for potential gender differences.

5.2 Methods

5.2.1 Subjects

Thirty males and 23 females volunteered to participate in this investigation. All participants were healthy and reported regular physical activity patterns at the time of enrollment. Prior to participation, each subject provided written informed consent. The study was approved by the University of Alberta Faculty of Physical Education and Recreation Research Ethics Board.

5.2.2 Experimental Design

All participants completed the following events:

- Approximately 3 hours of orientation to firefighting equipment, personal protective ensemble (PPE), self-contained breathing apparatus (SCBA), and the FF Test;
- Several (typically 3-5 depending on previous experience) practice sessions of the circuit in firefighting ensemble while breathing with the SCBA until the subject was able to perform the test at an optimal pace;
- Maximal circuit with oxygen consumption (MAX O_2) – performed as quickly as possible, wearing PPE, while breathing through a Hans Rudolph full-face mask and carrying a portable metabolic measurement system;
- Maximal circuit with SCBA (MAX SCBA) – performed as quickly as possible, while wearing PPE and breathing through the SCBA; and,
- Graded exercise test (GXT) to determine maximal oxygen consumption (VO_2max) in PPE while breathing through a Hans Rudolph full-face mask and carrying a portable metabolic measurement system.

The MAX O_2, MAX SCBA, and the GXT were performed in random order. All tests were carried out indoors in a standard temperature environment (21-24 °C).

5.2.3 Firefighting Protective Equipment (FPE)

During each of the exercise tests, subjects dressed in duty coat, fire fighting pants (System 300 CGSB; SafeCo Mfg. Inc., Scarborough, ON), helmet (Model 911; SafeCo Mfg. Inc., Scarborough, ON), anti-flash hood (PGI Inc., Green Lake, WI), leather work gloves, and rubber firefighting boots (Black Diamond; Kaufman Footware, Kitchener, ON), except during the GXT where running shoes were worn in the interest of comfort and safety on the treadmill. Subjects used a Scott 4.5 harness and a full 60-min Scott Air-Pac® fibre composite air cylinder (Scott Health and Safety, Monroe, NC). Total weight of the protective ensemble was 23.0 ± 1.80 kg.

5.2.4 Simulated Firefighter Test (FF Test)

The FF Test as described by Deakin et al. (1996) was set up indoors on a concrete floor where all the course dimensions and equipment (type and weight) were accurate according to the design specifications. Subjects were instructed to perform the FF Test as quickly as possible within the safety boundaries of the test. The FF Test consisted of the following tasks, in order:

- Hose carry: Using a rope handle, the subject carried one section (15.24 m) of rolled 65 mm rubber jacketed hose (Red Chief; Angus Fire, Thame, Oxfordshire, UK) weighing 16.5 kg in one hand a distance of 15.24 m, then returned the same distance carrying the hose in the other hand. The subject set down the rolled hose and walked 15.24 m to the next event.
- Ladder carry and raise: The subject lifted and carried a 3.6 m aluminum roof ladder (13.6 kg) a distance of 15.24 m and raised it against a brick wall. The subject then walked 15.24 m to the next event.
- Hose drag: The subject lifted and placed over the preferred shoulder a hose nozzle (Pistol Grip; Elkhart Brass Mfg. Co. Inc., Elkhart, IN) then

proceeded to drag two charged lengths (30.48 m in total) of 38 mm hose (Red Chief; Angus Fire, Thame, Oxfordshire, UK) a distance of 30.48 m. The force required to move the hose was approximately 260 N. The subject then walked 15.24 m to the next event.

- Ladder climb 1: using a 7.2 m ladder already in place against a wall (Duo-safety Ladder Corp., Oshkosh, WIS), the subject climbed 10 rungs (3.45 m) up and down, 3 times. The subject then walked 30.48 m to the next event.
- Rope pull: while standing in a stationary position, the subject pulled on a 16 mm nylon rope that was attached to a bundle of hose (one 30.48 m length of 100 mm hose (39.5 kg) and one 15.24 m length of 65 mm; Red Chief; Angus Fire, Thame, Oxfordshire, UK) 15.24 m using a hand-over-hand movement. The subject then walked 15.24 m and repeated the pull. The force required to move the hose bundle was approximately 200 N. The subject then walked 15.24 m to the next event.
- Forcible entry: using a 4.5 kg steel-head sledge hammer (DF0832C; Garant, Saint-Francois, QUE) the subject hammered a 90cm rubber tire filled with sandbags (total weight 102.5 kg) a distance of 30.5 cm across a 76.2 cm high wooden picnic table. The tabletop was reinforced with 19 mm (¾") "good-one-side" plywood. The subject then walked 15.24 m to the next event.
- Victim rescue: Walking backward, the subject dragged a 68.2 kg mannequin (Rescue Randy 1434; Simulaids Inc., Woodstock, NY) a total

distance of 30.48 m (15.24 one way, around a pylon and then back 15.24 m). The subject then walked 15.24 m to the next event.

- Ladder climb 2: using the 7.2 m ladder (Duo-safety Ladder Corp., Oshkosh, WIS), the subject climbed 10 rungs (3.45 m) up and down, 2 times. The subject then walked 30.48 m to the next event.
- Ladder lower and carry: The subject lowered and carried a 3.6 m aluminum roof ladder (13.6 kg) 15.24 m. The subject then walked 15.24 m to the next event.
- Spreader tool carry: The subject picked up and carried a 36.4 kg spreader tool (Hurst 32B; Hale Products Inc., Conshohocken, PA) 15.24 m and then returned 15.24 m.

During the FF Test, the following time measurements were recorded: the elapsed time for each individual event; the time to move from one event to the next; and, the total time to complete the entire circuit. The individual event times were totaled and expressed as "work time". The transition times between events were totaled and expressed as "relief time".

In addition, each subject provided a rating of perceived exertion (RPE: Borg, 1982) corresponding to each individual component of the FF Test. The 15-point scale was shown to the subject immediately after each event was completed and a recorder noted the response. The subject was familiarized with the scale during the orientation and practice sessions so that this information could be obtained quickly without causing any delay during the test. In the results, the average

RPE represent the mean of all responses, while the peak RPE was the highest value obtained during each trial.

5.2.5 Constant Workload and Graded Exercise Test (GXT)

The treadmill test was performed on a motor driven treadmill (Model #18237-2-6-95; Standard Industries, Fargo, ND), which was composed of four phases:

- Warm-up: subjects walked at a constant speed (93.8 $m\bullet min^{-1}$) for 5-minutes with a progression from 0-6% grade. The subject then proceeded immediately to the constant work phase.
- Constant workload phase: subjects walked for 8-minutes at 10% grade and 93.8 $m\cdot min^{-1}$. If able, subjects continued on to the GXT phase.
- GXT phase: subjects walked at a constant speed (93.8 $m\cdot min^{-1}$) and 11% grade for one minute, grade was then increased by 1% each minute up to 15%, and then speed was increased by 13.4 $m\bullet min^{-1}$ each minute until volitional exhaustion. Subjects then performed the cool-down phase.
- Cool-down: subjects walked for 5-min at 53.6 $m\cdot min^{-1}$ and 0% grade.

Physiological variables (e.g., heart rate, VO_2) during the constant work phase were averaged over the entire 8-min. The highest 1-minute value for VO_2 (from any part of the test) was accepted as VO_2max if a plateau in oxygen consumption was observed despite an increase in work rate or alternately, if the subject was too fatigued to continue exercise (ACSM, 2006). In addition, RPE was collected at the end of each minute during the test.

5.2.6 Physiological Measurements

Continuous (breath-by-breath) gas exchange measurements (e.g., VO_2, VCO_2, V_E, and RER) during the GXT and MAX O_2 trial were made with a VmaxST (SensorMedics, Yorba Linda, CA) portable metabolic measurement system (MMC). The software version was Meta Soft 1.5.1 (Cortex Biophysik, Leipzig, Germany). Each subject wore a specially designed Hans Rudolph 8930 series full-face mask with an Ultimate Seal™ gel (P/N 669204/201236) and head cap assembly (P/N 200525). The gas analyzers were calibrated immediately prior to each test using gases of known concentration, and calibration was verified immediately following the test. The Triple-V flow volume transducer was calibrated using a 10-stroke calibration of a 3.00-liter Hans Rudolph 5530 series syringe. In the results, average VO_2 represents the mean of all values acquired during the trial, while peak VO_2 is the highest 1-min value from each test.

In all conditions, subjects wore a Polar telemetry system (Vantage NV; Polar USA Inc., CT), which continuously measured and recorded heart rate at 5-second intervals during exercise. A Polar Advantage computer interface operating with Polar HR Analysis Software Version 5.04.01 (Polar Electro, OY, Finland) was used to transfer the heart rate data to a computer for analysis.

5.2.7 Statistical Analysis

Unpaired t-test was used to examine mean differences between the males and females (Tables 5-1, 5-3 and 5-4). A paired t-test was used to examine selected measurements from the MAX O_2 and MAX SCBA trials, separately, for the males and females (Table 5-2). Pearson Product-Moment correlation was used to examine the relationship between MAX O_2 and MAX SCBA performance times (Figure 5-1). In order to determine the oxygen cost associated with the 8-min completion standard, coincidence testing of simple linear regression equations was employed. The first step involved development of separate regression equations from the MAX O_2 trial for both the males and females. The second step utilized coincidence testing (Kleinbaum et al., 1998) to test for differences in the slope and intercept of the regression equations. Coincidence testing revealed no significant difference between genders and the total data set was collapsed (Figure 5-3).

Using the dichotomized performance standard (≤8-min or >8-min) on the FF Test as the gold standard for work-related fitness, diagnostic utilities analysis examined the sensitivity, specificity, overall accuracy, positive predictive value and negative predictive value of VO_2max and the completion of the constant work phase from the treadmill test (Table 5-5, Fletcher et al., 1988).

Statistics were performed using StatView for Windows version 5.0.1 (SAS Institute Inc., Carry, NC). Alpha values less than 0.05 was considered significant.

5.3 Results

Thirty males and 23 females participated in this project, however in some cases, not all subjects had complete data sets. On each table and figure, the number of observations is provided.

5.3.1 Participant Characteristics

The physical characteristics of the male and female participants are displayed in Table 5-1. On average, the female subjects were shorter, lighter and had lower BMI values ($p<0.05$) than the male subjects.

5.3.2 Performance Time

Within the gender groups, the total time to complete the FF Test during the MAX SCBA and MAX O_2 trials were the same (Table 5-2). Figure 5-1 shows there was a significant relationship ($r = 0.94$) between performance times for MAX SCBA and MAX O_2 conditions, when all the data was pooled.

On average, the males completed the MAX O_2 trial 16% faster ($p < 0.05$) than the females. The time the participants devoted to completion of specific tasks accounted for approximately 66% of the total time, with the transition time (15 or 30 m walks) between events making up the rest; this was consistent regardless of gender or condition (Table 5-2). Although the majority of the males completed the FF Test faster than the female participants, one female subject performed the FF Test quicker than 56% of the males.

Ninety-six percent of the males and 82% of the females completed the FF Test in less than 8 minutes. However, despite several practice sessions, one male and four female participants were unable to complete the FF Test within the 8-min standard (Figure 5-1).

5.3.3 Oxygen Cost of FF Test

For illustrative purposes, the VO_2 response records from one male and one female participant are shown in Figure 5-2. These plots show the typical pattern of VO_2 responses during the FF Test. These subjects were selected because: their response patterns were highly typical; both subjects completed their MAX O_2 trial in approximately seven minutes; and, their stature, mass, and VO_2max were similar.

The individual data points from the VO_2 records, from the MAX O_2 trial, were averaged to produce a single oxygen cost value (Average VO_2). Figure 5-3 shows the average oxygen consumption from the MAX O_2 trials for male and female subjects. The data in Figure 5-3 show that the faster the performance time, the greater the rate of oxygen consumption ($r = -0.72$: $p < 0.05$). The males averaged faster performance times on the FF test than the females and had significantly ($p < 0.05$) higher rates of VO_2 than the female average. However, during the MAX O_2 trial, the males and females worked at the same relative intensity (86.2 ± 6.7 and 83.9 ± 6.8% of VO_2max, respectively).

Simple linear regression was employed to determine the oxygen cost required to complete the FF Test at the 8-min standard. The regression equation (male and female data combined) to predict the oxygen cost (Y) of completing the circuit at a specific time (X) from this data was as follows: $Y = 63.091 - 3.62$; $r^2 = 0.51$; SEE 3.98. When $X = 8$ minutes, the predicted average oxygen cost of completing the FF Test at the 8-min standard was 34.1 $ml \cdot kg^{-1} \cdot min^{-1}$.

Utilizing data reported in the literature (Bilzon et al., 2001; Gledhill and Jamnik, 1992a; O'Connell et al., 1986; Petersen and Dreger, 2004; Sothmann et al., 1990; von Heimburg et al., 2006) regression analysis revealed that the VO_2 associated with 8 minutes of firefighting work was 32.3 $ml•kg^{-1}•min^{-1}$ (Figure 5-4).

5.3.4 Cardiorespiratory Responses During the FF Test

The heart rate response during the MAX O_2 trial for the males and females was 91.5 ± 4.1 and 89.6 ± 3.8% of HRmax. However, peak heart rates (highest 1-min average) reached up to 95% of HRmax. The MAX SCBA trial elicited similar results.

The males had significantly higher ventilation rates and tidal volumes compared to the females during the MAX O_2 trial, but similar breathing frequency (Table 5-3). When expressed as a percentage of the GXT value, there were no significant differences between genders. For example, V_E for the males and females during the MAX O_2 trial were the 82.6 ± 7.8 and 83.1 ± 9.0% of GXT values (ns), respectively.

The respiratory exchange ratios were significantly higher for the females compared to the males (Table 5-3). When expressed as a fraction of the GXT values, there were no differences.

5.3.5 Psychophysical Responses During the FF Test

The average rating of perceived exertion during the maximal trials were associated with the descriptor "hard" (Table 5-2). Peak RPE was associated with the descriptor “very, very hard” (male = 18 ± 2 and female = 19 ± 2 ns). There were no significant differences between the SCBA and MAX O_2 trials regardless of gender.

5.3.6 Cardiorespiratory Responses During the Treadmill Test

Table 5-4 represents selected responses during the eight-minute constant workload phase (values averaged over the entire time) and maximal values from the GXT. During the constant workload phase, all of the variables were significantly different for the males and females, except for the VO_2 expressed in ml•kg^{-1}•min^{-1} (34.0 vs. 33.4 ml•kg^{-1}•min^{-1} males and females, respectively).

Maximal values for VO_2, V_E, and V_T were significantly higher for the males compared to the females. There was no significant difference in HRmax or breathing frequency. The females had significantly higher RER response.

Figure 5-4 indicated there was a significant inverse relationship (r = 0.57) between the VO_2max values from the GXT and MAX O_2 performance time on the FF Test. The predicted VO_2max required to complete the FF Test at the 8-min standard was 41.2 ml•kg^{-1}•min^{-1}.

5.3.7 Diagnostic Utilities

For the entire group, the positive predictive value of the constant workload phase and a VO_2max cut-off of 41 ml•kg^{-1}•min^{-1} to identify the capability to complete the FF Test at or below the 8-min standard showed a high probability

(0.90 to 0.95; Table 5-5); however, the accuracy of the indicators ranged from moderate to high (75% to 90%).

The utility of the constant workload phase was found to have 100% sensitivity; however, in identifying "true" passers on the FF Test, some failures were incorrectly classified as a pass. This is indicated by the specificity (0%) and Negative Predictive Value (0.00). The VO_2max cutoff was not as sensitive (77%), but was better able to classify "true" failures, as indicated by the specificity (60%) and negative predictive value (0.21).

When the diagnostic utilities were calculated based on gender, the constant workload test showed no difference in sensitivity, specificity, or negative predictive value and only slight differences in accuracy and positive predictive value. The VO_2max cutoff showed differences between genders on all of the diagnostic utilities (Table 5-5).

5.4 Discussion

5.4.1 Importance of Cardiorespiratory Fitness to Firefighting

Firefighting is considered to be a physically demanding job that often involves work with heavy tools while encumbered in heavy protective equipment (Gledhill and Jamnik, 1992a; NFPA 2003). Many emergency situations require the performance of individual tasks or, in some cases, a series of tasks coupled together. One of the most physically demanding activities is that of search and rescue. Regardless of age or rank, firefighters find this task to be the most demanding (Lusa et al., 1994). To ensure firefighters are physically ready for the challenges, various assessments have been developed. Similar to other work simulations (Louhevaara et al., 1994), the FF Test was developed to simulate and assess the physical demands of firefighting duties, including search and rescue. Achieving the 8-min standard implies an adequate level of fitness for duty; with an assumption that the individual fitness components (e.g., strength and aerobic fitness) embedded in the test is also being assessed at an appropriate level. There is considerable evidence that firefighting requires a substantial aerobic component. It is believed that the aerobic demand of the FF Test at the 8-min standard is equivalent to the demands of firefighting duty. To date, there are no published studies describing the oxygen cost required to performance the FF test at the 8-min standard. The main purpose of this study was to determine the VO_2 required to complete the FF Test.

5.4.2 Methodological Considerations

From a methodological perspective, it is important to bear in mind that there were no substantial or systematic differences between performance, heart rate, or perceived exertion when the subjects completed the CF/DND FF Test breathing through the portable metabolic measurement system (VmaxST) or the SCBA. The data reported in Figure 5-1 and Table 5-2 show consistency between breathing through the VmaxST system or the SCBA when completing the FF Test as quickly as possible. We concluded that the VmaxST system neither advantaged nor disadvantaged the subjects compared to the SCBA. Since the SCBA represents standard practice for the correct administration of this test, it was essential to demonstrate that the respiratory gas exchange measurements were made under similar physiological conditions to the SCBA condition. Furthermore, the use of a portable metabolic measurement system as described in the current study has become common practice in identifying the oxygen cost of the fire fighter work (Bilzon et al., 2001; von Heimburg et al., 2006).

5.4.3 Oxygen Cost of the FF Test

The data shown in Figure 5-3 revealed a moderately strong, negative relationship between the average rate of oxygen uptake and performance time on the FF Test. The faster the completion time, the higher the rate of oxygen consumption, and this observation underscores the importance of aerobic fitness to performance of this work simulation. For the entire group of subjects in the present study, the average VO_2 was 39.2 ± 5.64 $ml•kg^{-1}•min^{-1}$, however, this corresponded to a performance time of 6.61 ± 1.12 minutes. Regression analysis revealed that an average VO_2 of 34.1 $ml•kg^{-1}•min^{-1}$ was required to perform the work simulation in 8-minutes.

Other investigations have shown similar workrate/VO_2 responses to simulated firefighting. von Heimburg et al. (2006) reported average oxygen cost observed during hospital patient rescue was 34.3 $ml•kg^{-1}•min^{-1}$, with an average completion time of 6.58 min (range 5.00 to 9.00 min). Sothmann et al. (1991) reported the average duration of a fire-rescue protocol was 8.93 minutes (range of 5.50 to 13.90 min) with a mean VO_2 value of 30.5 $ml•kg^{-1}•min^{-1}$. Bilzon et al.

(2001) reported the average VO_2 associated with five shipboard firefighting activities, each lasting for four minutes, was 36.6 ml•kg^{-1}•min^{-1}. When we consider the average VO_2 from the research studies that actually measured oxygen consumption, regardless of exercise duration, a mean value 34.4 ml•kg^{-1}•min^{-1} was calculated (O'Connell et al., 1986; Sothmann et al., 1990; Gledhill and Jamnik, 1992a; Bilzon et al., 2001; Petersen and Dreger, 2004; von Heimburg et al., 2006). When data from the various studies were pooled (Figure 5-4) the relationship between average oxygen consumption and work time was highly significant. The r^2 value from the regression analysis was 0.93; further confirming the strength of this relationship. Using the equation generated form the regression analysis, the estimated VO_2 for eight minutes of simulated firefighting work is approximately 32 ml•kg^{-1}•min^{-1}, which is similar to the measured value for completion of the FF test at the 8-min standard. These results suggest that the aerobic demand of completing the FF Test at the 8-min standard is consistent with other research on simulated firefighting.

The National Fire Protection Agency (NFPA) Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations and Special Operations to the Public by Career Fire Departments states "an early aggressive and offensive primary interior attack on a working fire...is usually the most effective strategy to reduce loss of lives and property damage." (NFPA 1710: 2001, page 15). Modeling studies indicate that 50% of the total damage incurred in a fire occurs within 8 minutes (NFPA, 2001). Furthermore, there is an exponential increase in property damage and human cost (i.e., injury and death) once the fire has advanced outside of the room of origin (NFPA, 2001). These are powerful statements of the time-sensitive nature of fire suppression operations.

When asked to perform firefighting work as quickly as possible, firefighters adjust their work intensity to maintain near maximal efforts (Manning and Griggs, 1983). At maximal effort, the subjects in the current investigation worked at an average level of 85% of VO_2max, with peak VO_2 values approaching 95% of VO_2max. These results are consistent with those reported by von Heimburg et al. (2006) but are higher than those reported by Sothmann et al. (1990). However, the latter investigation involved a level of visual impairment (smoke), which may have slowed the work rate. In the current study, there were no differences between males and females, whereas in the investigation by Bilzon et al. (2001) the females worked at a significantly higher percentage of VO_2max compared to the males. In the study by Bilzon et al. (2001) a member of the research team controlled the subjects' work rate; therefore, work rate was not self-selected. The inability to self-select work rate may in part account for the differences between the males and females responses.

5.4.4 Performance Factors

The "scatter" above and below the regression line in Figure 5-3 reveals that while average VO_2 may be significantly related to test performance time, it is also clear that other factors contribute to performance. The nature of the work being done in many of the FF Test tasks (e.g., moving heavy equipment) are suggestive of the importance of strength and anaerobic power in addition to aerobic fitness. Review of the physical characteristics of the subject pool suggests that body mass and stature may influence how individuals accomplish this work (von Heimburg et al., 2006). The relative importance of strength to the performance of simulated fire suppression tasks has been reported previously (Davis et al., 1982; Williford et al., 1999; Rhea et al., 2004; von Heimburg et al., 2006). It is suggested that future research examine the importance other fitness components such as muscular strength, endurance, and power have on FF Test performance time.

Examination of the respiratory exchange ratios during the FF Test suggested there may be a substantial anaerobic contribution. A previous study of the FF test revealed that post FF Test blood lactate values averaged 16 mM/L (Deakin et al., 1996). In another investigation of a similar firefighter work circuit, Petersen et al. (2000) reported that blood lactate levels at the end of the work averaged 15.5 mM/L. These aspects should not be overlooked when evaluating the factors contributing to performance on any firefighting work simulation. While the focus of the current project was on the aerobic demands of this work simulation, it would be an oversimplification to suggest that aerobic fitness alone determines test performance time.

5.4.5 Treadmill Test and FF Test Performance

On average, the participants in the current study could be classified as having "good" aerobic fitness based on VO_2max (McArdle et al., 2001, p. 163), while individual scores ranged from "average" to "excellent". The males had significantly higher absolute and relative VO_2max scores, which is consistent with normative data as well as the other investigation specific to firefighting (Bilzon et al., 2001).

It has been suggested that VO_2max be used to evaluate the aerobic fitness of firefighters. Based on the average oxygen cost of firefighting work and the typical effort sustained by firefighters, it has been recommended that firefighters have a minimum VO_2max between 2.71 to 4.0 $L \bullet min^{-1}$ (O'Connell et al., 1986; Gledhill and Jamnik, 1992b; von Heimburg et al., 2006). However, these suggestions are based on male data only. Normative data suggests that most females would not be able to meet the most stringent of these absolute criteria.

It is commonly accepted that weight bearing activities, such as firefighting work, be scaled to body weight. Furthermore, it has been suggested that scaling is a more prudent method when comparing various groups such as males and females (Shephard and Bonneau, 2002). The majority of recommended VO_2max values have utilized a scaled approach (O'Connell et al.,1986, 39 $ml \bullet kg^{-1} \bullet min^{-1}$; Sothmann et al., 1990, 33.5 $ml \bullet kg^{-1} \bullet min^{-1}$; Sothmann et al., 1992, 42 $ml \bullet kg^{-1} \bullet min^{-1}$; Gledhill and Jamnik, 1992b, 45 $ml \bullet kg^{-1} \bullet min^{-1}$; Bilzon et al., 2001, 41 $ml \bullet kg^{-1} \bullet min^{-1}$; NFPA, 2003, 42 $ml \bullet kg^{-1} \bullet min^{-1}$; von Heimberg et al., 2006, 48 $ml \bullet kg^{-1} \bullet min^{-1}$). Due to the wide range of recommended VO_2max values, averaging of the data allows for a simplified means of comparison (41.3 $ml \bullet kg^{-1} \bullet min^{-1}$).

In order to evaluate the utility of the VO_2max average, we examined the ability of the cut-off value to correctly identify individuals capable of completing the FF Test at or below the 8-min standard. In the current study, twelve females and two males had VO_2max values below 41.3 ml•kg^{-1}•min^{-1}. Based on VO_2max, these individuals would be considered to have insufficient aerobic fitness to perform firefighting work. However, nine of the twelve females and both of the males completed the FF test in 8 min or less, indicating that VO_2max may not be the best predictor of ability to perform firefighting work. In addition, the results suggest a possible gender bias, which was confirmed via the diagnostic utilities analysis of sensitivity, specificity, accuracy, and negative predictive value.

As an alternative to a VO_2max cutoff, the current research has suggested the use of a constant workload treadmill assessment. Diagnostic utilities analysis (Table 5-5) revealed that the constant workload test classified individuals who met the 8-min standard on the FF Test 100% of the time. Furthermore, the constant workload treadmill test showed no substantial differences between genders on any of the variables.

These results suggest that the constant workload treadmill test provides a more accurate and unbiased means of assessing the aerobic component related to firefighting work than the average VO_2max obtained from reviewing the firefighting literature.

5.4.6 Heart Rate Responses during the FF Test

When expressed as a percentage of maximum heart rate, the subject's responses while performing the FF Test were very similar to reports from actual firefighting. Sothmann et al. (1992) monitored the heart rate response of 10 male firefighters during an actual emergency and on average the firefighters were engaged in active duty for 15 min (range: 8 to 28 min). The average heart rate response for the subjects was 157 beats•min^{-1}, which corresponded to 88% of maximum heart rate obtained from a maximal exercise testing. More recently, Bos et al. (2004) examined the heart rate responses of 222 firefighters during 85 24-hour shifts. The results of the extensive monitoring revealed that working intensities, as described by percentage of heart rate reserve (%HRR), for the firefighters ranged from 3 to 92 %HRR. The activities that prompted the highest mean %HRR were walking on stairs (44 %HRR) and SCBA use (58 %HRR).

The heart rate responses during simulated firefighting tasks tend to show slightly higher responses than actual emergencies. For example Bilzon et al. (2001) found that the firefighting tasks studied, although paced, produced an average heart rate response equal to 90% of maximum heart rate. In a study by Petersen et al. (2000), the subjects worked as quickly as possible through a series of work tasks with an average heart rate response equal to 91% of HRmax.

The results from the current investigation are similar to those reported for both actual and simulated firefighting work. What is of particular interest is that the female data from the Bilzon et al. (2001) study and the current investigation were very similar. In addition, Bilzon et al. (2001) showed the males tended to work at a lower percentage of maximal heart rate compared to the female participants.

5.4.7 Ventilatory Responses during the FF Test

This is the first study to report the ventilatory responses for females performing simulated firefighting work. Females had lower V_E and V_T compared with the males during the same trial conditions; this may be related to the generally smaller stature and trunk size (Kilbride et al., 2003). On the other hand, the females tended to have higher breathing frequencies, which is also similar to the finding of Kilbride et al. (2003). During the MAX O_2 trial, ventilatory responses, when expressed as a fraction of the GXT values, were the same for both males and females. The absolute V_E values obtained for the males during the MAX O_2 were similar to those reported by von Heimburg et al. (2006), however they were substantially higher than the values reported by Sothmann et al. (1990). The differences may be partially explained by methodological factors. Sothmann et al. (1990) measured ventilation at three points throughout the work simulation; whereas von Heimburg et al. (2006) and the current investigation utilized breath-by-breath measurements throughout the firefighting simulation.

5.5 Summary

The results of this study show that completion of the FF test at the 8-minute standard requires a substantial cardiorespiratory demand. It appears that average VO_2 associated with the standard is consistent with other research on firefighting work. The VO_2 for the constant work phase of the treadmill test was nearly identical to the average VO_2 required to meet the FF Test 8-min standard. The constant workload phase of the GXT was able to accurately (true-positive) identify individuals capable of meeting the 8-min standard on the FF Test. Based on the data, when performing the same absolute external work (FF Test or treadmill), there were no significant differences in oxygen consumption between gender groups. In conclusion, the constant workload treadmill test provides a novel means of assessing the aerobic fitness of firefighters without gender bias.

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Table 5-1. Characteristics of participants (Mean ± *SD*).

Variable	Male (*n*=30)	Female (*n*=23)
Age (yr)	29.0 ± 6.8	25.8 ± 5.6
Height (cm)	181.9 ± 5.8	169.0 ± 6.4*
Body mass (kg)	84.6 ± 6.6	68.2 ± 7.6*
BMI (kg/m^2)	25.6 ± 1.7	23.9 ± 1.9*

Significant difference between males and females: * $p < 0.05$. BMI = body mass index.

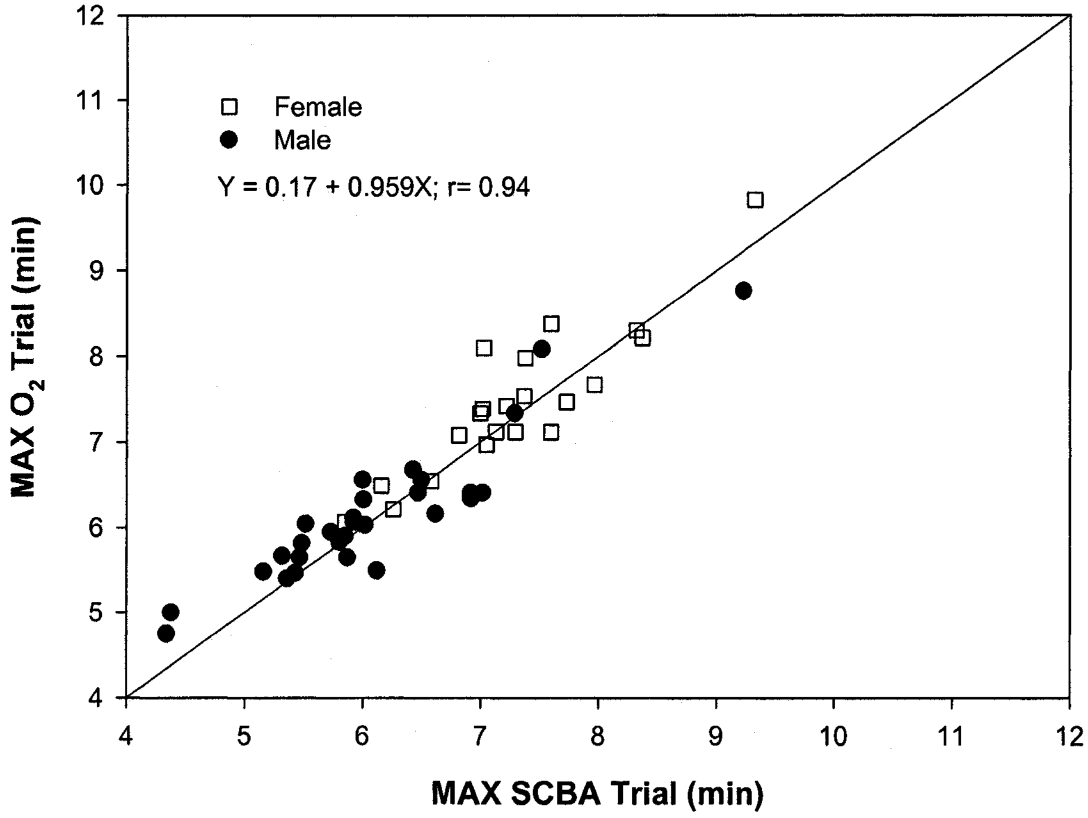

Figure 5-1. Relationship between completion times for the FF Test during the MAX O_2 and MAX SCBA for males (circle: 29 data points) and females (square: 21 data points). Line of identity is shown.

Table 5-2. Values (Mean ± SD) for selected measurements from the MAX O_2 and MAX SCBA trials.

Variable	Male MAX O_2 (*n*=30)	Male MAX SCBA (*n*=29)	Female MAX O_2 (*n*=22)	Female MAX SCBA (*n*=22)
Total time (s)	365.2 ± 56.3	369.2 ± 49.6	442.3 ± 50.8	449.1 ± 51.1
Work time (s)	241.0 ± 39.8	246.1 ± 33.8	293.7 ± 36.6	299.4 ± 37.5
Relief time (s)	124.2 ± 20.9	124.3 ± 20.7	148.6 ± 20.2	149.7 ± 24.2
RPE	13.8 ± 1.8	14.0 ± 1.5	14.5 ± 2.3	14.4 ± 1.9
HR (beats $\cdot$ min^{-1})	168.7 ± 10.2	169.2 ± 11.7	171.0 ± 12.7	167.3 ± 11.8

Total time = total time to complete the FF Test; work time = the total time to perform the various firefighting tasks; relief time = total time during the 15 m and 30 m walks; RPE = rating of perceived exertion; HR = heart rate.

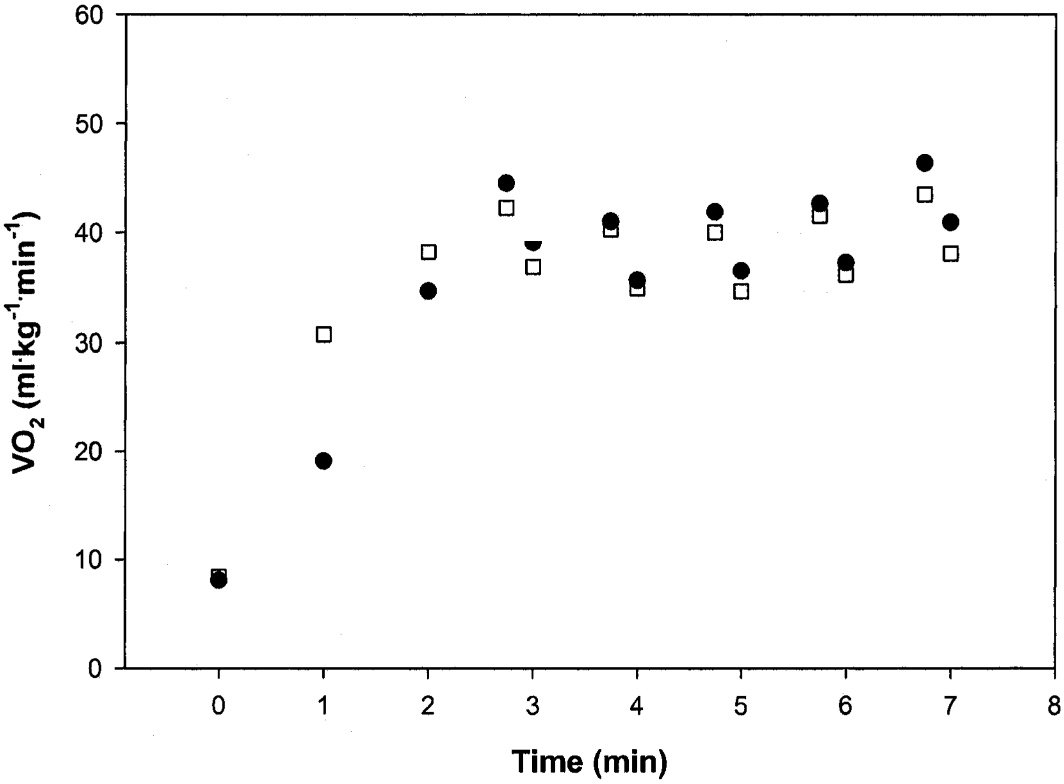

Figure 5-2. Oxygen consumption record for one male (circle) and one female (square) subject, similar in age, height, weight and VO_2max, completing the FF Test in approximately 7 minutes.

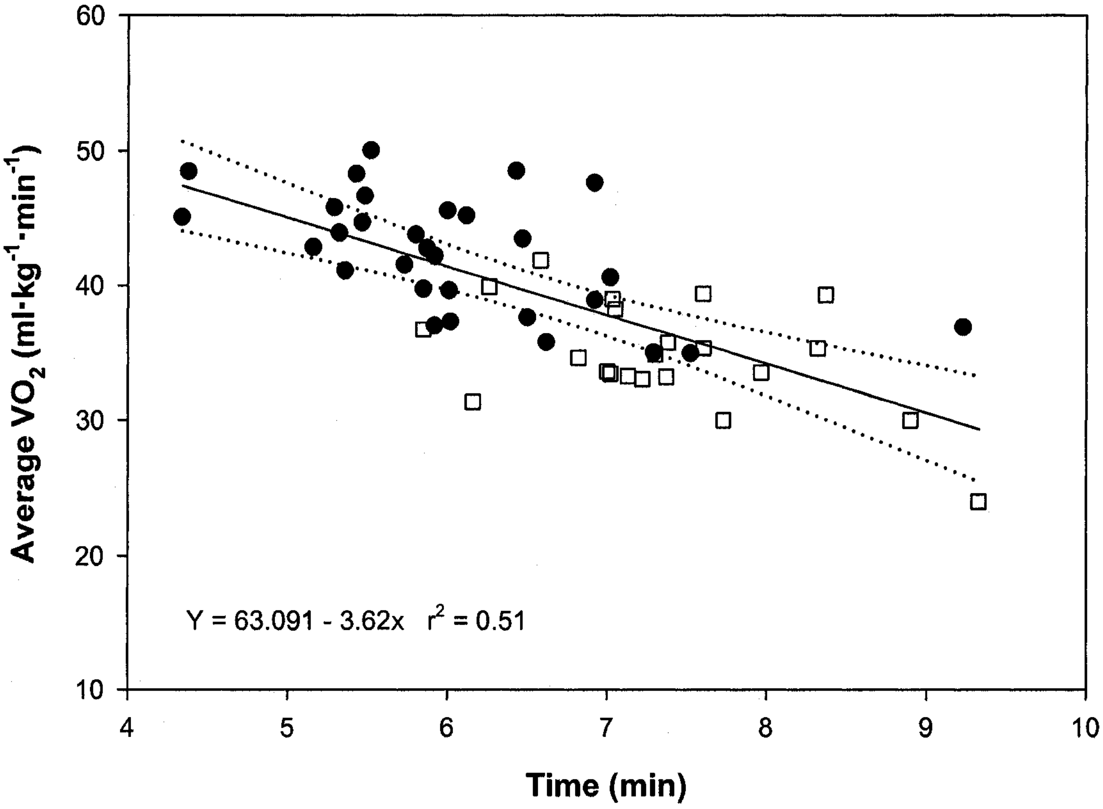

Figure 5-3. Average oxygen consumption for males (circle: 30 data points) and females (square: 22 data points) during the FF Test. 95% confidence intervals are shown. Predicted VO$_2$ is 34.1 ml•kg^{-1}•min^{-1} when X = 8 min.

Table 5-3. Values for selected measurements from the MAX O_2 trial (Mean ± *SD*).

Variable	Male (*n*=30)	Female (*n*=22)	Combined (*n*=52)
Time (min)	6.06 ± 0.96	7.36 ± 0.85*	6.61 ± 1.12
VO_2 ($ml•kg^{-1}•min^{-1}$)	42.4 ± 4.38	34.8 ± 4.02*	39.2 ± 5.64
VO_2 ($L•min^{-1}$)	3.54 ± 0.41	2.37 ± 0.33*	3.07 ± 0.71
RER	1.10 ± 0.07	1.18 ± 0.08*	1.13 ± 0.09
V_E ($L•min^{-1}$)	119.6 ± 15.9	91.0 ± 14.5*	107.5 ± 20.8
V_T (L)	2.40 ± 0.27	1.75 ± 0.22*	2.13 ± 0.41
f ($breaths•min^{-1}$)	50.2 ± 7.41	52.5 ± 3.80	51.2 ± 6.21
Heart Rate ($beats•min^{-1}$)	168.7 ± 10.2	171.0 ± 12.7	169.7 ± 11.3
RPE	13.8 ± 1.84	14.5 ± 2.26	14.1 ± 2.04

*Significant difference between males and females. VO_2 = volume of oxygen consumption; RER = respiratory exchange ratio; V_E = pulmonary ventilation; V_T = tidal volume, *f* = breathing frequency; RPE = rating of perceived exertion.

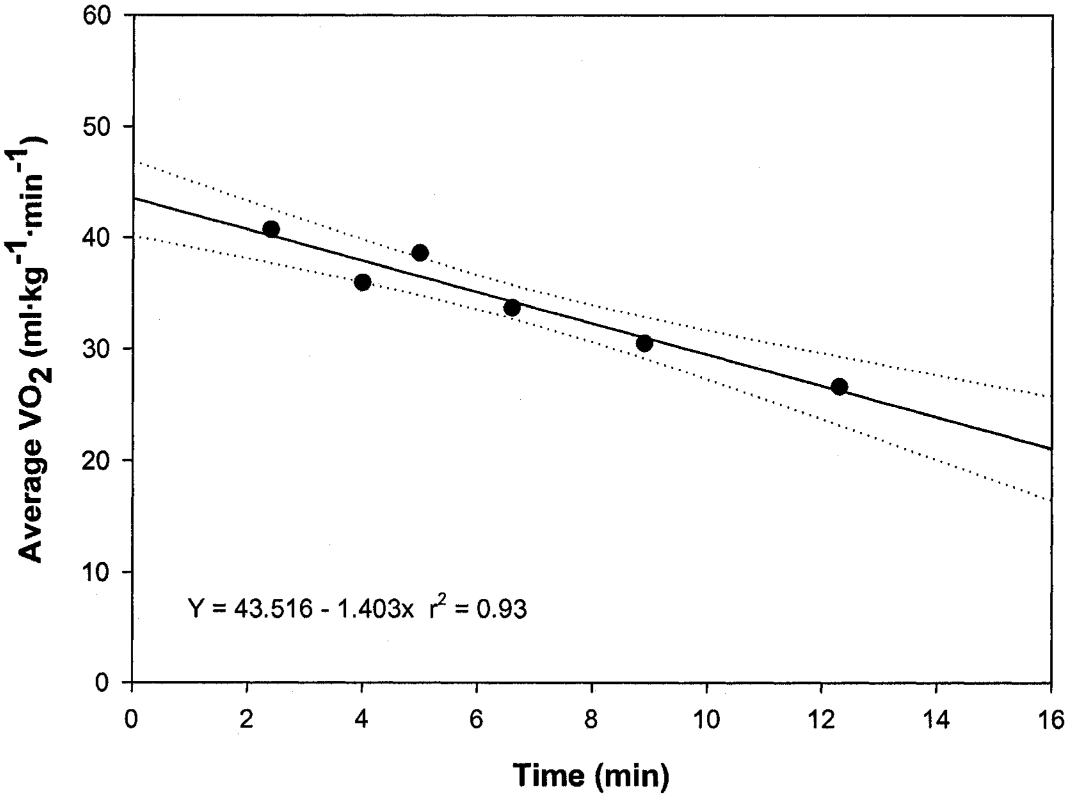

Figure 5-4. Regression analysis of average VO_2 and work time from research where gas exchange was measured during simulated fire-rescue work. From left to right: Gledhill and Jamnik, 1992a; Bilzon et al., 2001; O'Connell et al., 1986; von Heimburg et al., 2006 Sothmann et al., 1990; Petersen and Dreger, 2004. 95% confidence interval shown. Predicted VO_2 is equal to 32.3 ml•kg^{-1}•min^{-1} when X = 8 min.

Table 5-4. Selected responses during the 8-min constant workload phase and maximal values from the GXT for males and females.

Variable	Males	Females
Constant Workload		
Heart Rate (beats min^{-1})	157.5 ± 13.7	165.7 ± 13.1*
VO_2 (L•min^{-1})	2.88 ± 0.31	2.28 ± 0.15*
VO_2 (ml•kg^{-1}•min^{-1})	34.0 ± 3.0	33.4 ± 2.8
RER	0.99 ± 0.08	1.05 ± 0.09*
V_E (L•min^{-1})	76.7 ± 12.5	69.7 ± 11.8*
V_T (L)	2.26 ± 0.32	1.77 ± 0.25*
f (breaths•min^{-1})	34.3 ± 5.74	39.2 ± 4.70*
Maximal Values		
HRmax (beats•min^{-1})	189.2 ± 10.7	187.4 ± 10.8
VO_2max (L•min^{-1})	4.17 ± 0.54	2.84 ± 0.43*
VO_2max (ml•kg^{-1}•min^{-1})	49.2 ± 6.0	41.7 ± 4.8*
RER	1.14 ± 0.08	1.22 ± 0.07*
V_E (L•min^{-1})	146.3 ± 20.8	110.1 ± 14.4*
V_T (L)	2.73 ± 0.34	1.99 ± 0.28*
f (breaths•min^{-1})	54.1 ± 6.98	56.6 ± 6.48

Submaximal values are mean ± SD averaged over the 8-minute exercise. VO_2 = volume of oxygen consumption; RER = respiratory exchange ratio; V_E = pulmonary ventilation; V_T = tidal volume, *f* = breathing frequency, HRmax = maximum heart rate. * = significant ($p \leq 0.05$) difference between males and females.

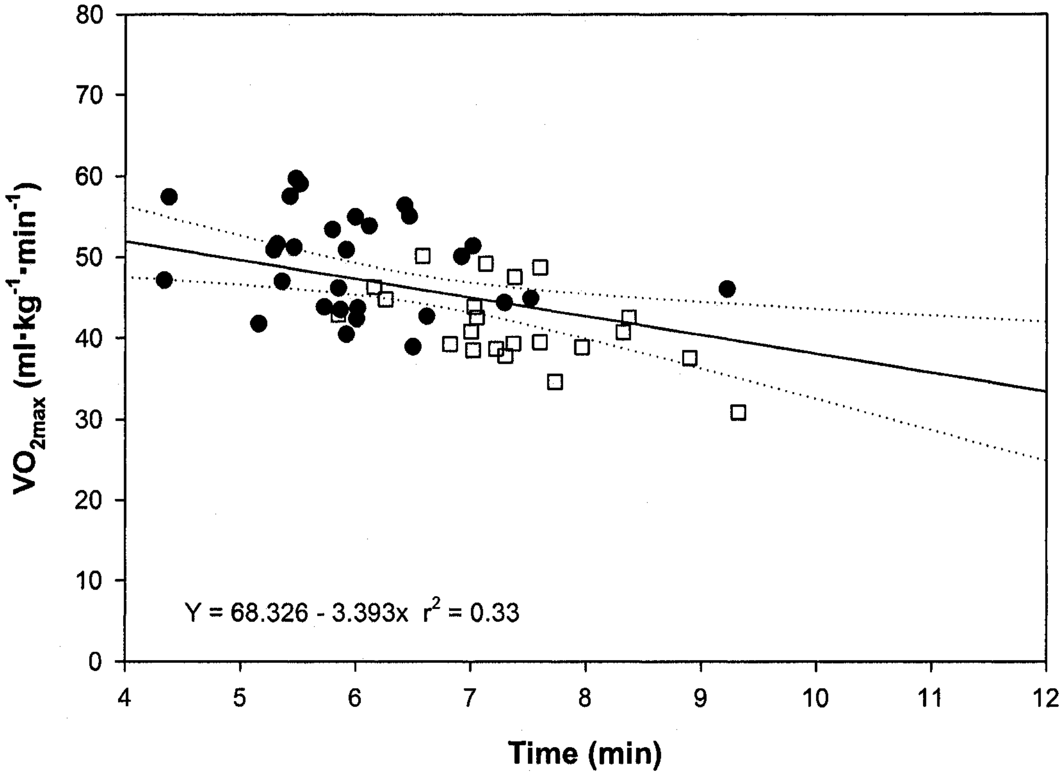

Figure 5-5. Regression analysis of maximal oxygen consumption, from the GXT, for males (circle: 29 data points) and females (square: 22 data points) and performance time from the MAX O_2 trial. 95% confidence interval is shown. Predicted VO_2max is 41.2 ml•kg^{-1}•min^{-1}when X = 8 min.

Table 5-5. Diagnostic utilities of VO_2max cutoff (≤41 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ or >41 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$) and constant workload (CW) treadmill test (complete or incomplete) to categorize FF Test performance time (≤8-min or >8min).

Diagnostic Utility	VO_2max (41 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$)	CW Treadmill test
Sensitivity		
Overall	77%	100%
Males	93%	100%
Females	47%	100%
Specificity		
Overall	60%	0%
Males	0%	0%
Females	75%	0%
Accuracy		
Overall	75%	90%
Males	90%	97%
Females	57%	83%
Positive Predictive Value		
Overall	.95	.90
Males	.96	.97
Females	.91	.83
Negative Predictive Value		
Overall	.21	.00
Males	.00	.00
Females	.25	.00

VO_2max cutoff point was derived from the average VO_2max requirements cited in the literature (see text). CW = constant workload.

CHAPTER 6

GENERAL DISCUSSION

6.1 General Discussion

As stated throughout this thesis, fire suppression can be classified as physically demanding (Davis et al., 1982; NFPA, 2003; Smith et al., 1998). Because of the high level of physical stress, most fire departments assess the fitness level of firefighters to help ensure they have the physical capability to perform their duties (Gledhill and Jamnik, 1992a; Louhevaara et al., 1994; NFPA, 2000; Sothmann et al., 1990). One component of particular interest has been the aerobic demands of firefighting work and consequently the aerobic fitness of firefighters. The purpose of this research program was to examine issues related to the physical stresses of firefighting in order to develop a new assessment of aerobic fitness for firefighters.

The first investigation in this project determined which courses and activities were the most physically demanding parts of an accredited firefighter training program in accordance with the National Fire Protection Association (NFPA) 1001 standard – firefighter professional qualifications. Upon identification of the physically demanding components, the second part characterized the heart rate and psychophysical responses of students performing selected firefighter training activities.

The first stage of the investigation determined that five of the eleven courses, each a week in duration, involved physically demanding components. Students participating in the specified demanding courses responded to questionnaires, which identified the particular components that were physically taxing. The students identified activities that were performed in a sequence as the most demanding, referred to as scenarios. The students performed on average four to six training scenarios two to three days per week. The number of scenarios performed in training was substantially greater than that performed by actual firefighters (Sothmann et al., 1990; Austin et al., 2001). Furthermore, the duration of the scenarios (range from 10:54 to 74:00 min:sec) were similar to the data from actual responses (Austin et al., 2001).

The second phase of this investigation reported on the cardiac responses of the fire training students during the various scenarios. Average heart rate responses for the scenarios ranged from 108 beats•min^{-1} (55% of HRmax) to 170 beats•min^{-1} (87% of HRmax), with an overall average of 127 beats•min^{-1} (66% of HRmax). In one case, peak heart rate response reached a high of 108% of predicted HRmax. These responses were similar to results from other investigations of firefighter training (Romet and Frim, 1987) and actual firefighting (Barnard and Duncan, 1975; Sothmann et al., 1992).

There tended to be an inverse relationship between heart rate and scenario duration. Typically, average heart rate was higher during short duration scenarios and vice versa. However, in some cases (e.g., the structural course) higher heart rates were elicited even though the duration was longer than other scenarios.

The results of this investigation clearly demonstrated that firefighter training imposed a high cardiac stress, similar to actual emergencies. It is therefore important that appropriate screening protocols be administered to students prior to training, to ensure adequate aerobic fitness levels for safe and effective performance.

The second study was undertaken as part of a process to develop an aerobic fitness assessment for firefighters. Project Two (Chapter 4) investigated selected physiological responses to graded exercise while wearing personal protective equipment (PPE) and breathing from a SCBA (GXT_{PPE}) compared to standard exercise clothing (shorts and t-shirt) while breathing through a low-resistance valve (GXT_{PT}). This investigation was designed in conjunction with other studies being performed in our laboratory (Eves et al., 2002; 2003; 2005).

The main finding of this investigation was that VO_2max during GXT_{PPE} was 17.3% lower than the GXT_{PT} (43.0 ± 5.7 vs. 52.4 ± 8.5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively). The reduction in VO_2max in the current investigation was greater than what Eves et al. (2005) reported (14.9% reduction). This may be attributed to differences in the amount of PPE worn by the subjects (12.1 kg vs. 21.4 kg). In a different investigation Louhevaara et al. (1995) reported a 4% difference in VO_2max when subject wore PPE without breathing from the SCBA. When the results from Eves et al. (2005) and Louhevaara et al. (1995) are combined, the effects of the PPE as seen in the current investigation are similar.

The lower VO_2max during the PPE condition was significantly related ($r=0.81$, $p<0.05$) to attenuated peak ventilation (142.8 ± 18.0 vs. 167.1 ± 15.6 $L \cdot min^{-1}$), which was attributed to a significant reduction in tidal volume (2.6 ± 10.4 vs. 3.2 ± 0.4 L) as breathing frequency was unchanged (55 ± 7 vs. 53 ± 7 $breaths \cdot min^{-1}$). Eves et al. (2005) also found a significant relationship between attenuated V_E and the reduction in VO_2max, which was primarily explained by an increased breathing resistance imposed by the SCBA. In the current investigation the impact of the SCBA was not evident until 16% grade. The corresponding ventilation at that stage was approximately 108 L•min^{-1}, or 80% VO_2max. These findings were similar to those reported by Eves et al. (2005).

The results of this investigation demonstrated that PPE and the SCBA had a negative impact on VO_2max. These factors should be considered whenever evaluating the aerobic demands of fire suppression work and subsequent fitness levels of firefighters.

In order to set a standard for aerobic fitness it is important that the aerobic demand of firefighting be identified (Gledhill et al., 2000). The objectives of the final project were to examine the aerobic demands of simulated firefighting, and to provide a new approach to assessing the aerobic fitness of firefighters. The first phase of this project utilized the FF Test (Deakin et al., 1996) as a surrogate for firefighting work. This standardized simulation of firefighting work allowed for the direct measurement of oxygen consumption as well as other cardiorespiratory variables.

The average performance time on the FF Test was 6.61 ± 1.12 min, with the males (6.06 ± 0.96 min) completing the FF Test 16% faster ($p < 0.05$) than the females (7.36 ± 0.85 min). The work and relief time were significantly less for the males compared to the females, however, the proportion of time was the same.

Heart rate responses during the FF Test averaged 92 and 90% of HRmax for the males and females, respectively. The participant's heart rate responses from the FF Test were similar to the heart rates observed during the Introductory

Firefighting scenario described in Chapter 3, as well as a firefighting simulation previously utilized in our laboratory (Petersen et al., 2000).

Ventilation rate during the FF Test (male = 119.6 ± 15.9 and female = 91.0 ± 14.5 $L{\bullet}min^{-1}$) and the GXT (male = 146.3 ± 20.8 and female = 110.1 ± 14.4 $L{\bullet}min^{-1}$) were significantly higher for the males compared to the females. However, when the ventilation rate during the FF Test was expressed as a fraction of peak ventilation there was no difference between genders. The fraction of the maximal value (approximately 81%) was similar to the percentage where the SCBA tended to impact ventilation as discussed in Chapter 4.

The average VO_2 and performance time on the FF Test showed a significant negative correlation, indicating that the faster the performance, the higher the rate of oxygen consumption. Performance times ranged from 4.34 to 9.33 minutes with corresponding VO_2 values of 24.0 to 50.1 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$. The oxygen cost for the females was, on average, significantly lower than males, 34.8 ± 4.0 and 42.4 ± 4.4 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, respectively. However, on average, the females performed the FF Test significantly slower than the males (7.36 ± 0.85 and 6.06 ± 0.96 min, respectively).

One of the main objectives of this investigation was to determine the VO_2 associated with the 8-min performance standard. Simple linear regression analysis revealed that an average VO_2 of 34.1 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ was required to meet the 8-min time standard. Coincidence analysis revealed there was no significant difference in slope or intercept between the male and female regression lines.

Support for the validity of the aerobic demand required to meet the 8-min standard (34.1 ml•kg^{-1}•min^{-1}) was provided from an analysis of the literature that directly measured VO_2 during simulated firefighting work (O'Connell et al., 1986; Sothmann et al., 1990; Gledhill and Jamnik, 1992a; Bilzon et al., 2001; Petersen and Dreger, 2004; von Heimburg et al., 2006). This analysis suggested that the average VO_2 associated with eight minutes of firefighting work was 32.2 ml•kg^{-1}•min^{-1}.

The final part of this investigation examined the utility of a laboratory based assessment of aerobic fitness. The cardiorespiratory responses during the 8-min constant work load (93.8. m•min^{-1} and 10% grade) treadmill protocol revealed similar oxygen consumption values for males and females (34.0 ± 3.0 and 33.4 ± 2.8 ml•kg^{-1}•min^{-1}). These results were nearly identical to the oxygen cost associated with the FF Test at the 8-min standard (34.1 ± 2.8 ml•kg^{-1}•min^{-1}) and the values reported in the literature (32.3 ml•kg^{-1}•min^{-1}).

Diagnostic utilities analysis revealed that the constant workload test was able to correctly classify individuals who met the 8-min standard on the FF Test 100% of the time. In addition, the constant workload treadmill test showed no substantial differences between genders on sensitivity, specificity, accuracy, positive predictive value, and negative predictive value. Furthermore, the results suggested that the constant workload treadmill test provided a more accurate and unbiased means of assessing the aerobic component for firefighting work than VO_2max.

6.2 Conclusions

The overall goal of this research was to first examine issues related to the aerobic demands of firefighting work. Secondly, a new method of assessing the aerobic fitness of firefighters was developed. Based on the results of this investigation the following conclusions were drawn:

- Firefighter training involved a considerable cardiac strain equivalent to and in some cases greater than those incurred during actual firefighting;
- Personal protective ensemble combined with the SCBA has a significant negative impact on VO_2max;
- The oxygen cost of the FF Test at the 8-min standard was consistent with the oxygen cost values cited in the literature;
- The oxygen cost associated with firefighting work can be simulated during a treadmill test;
- The constant workload treadmill test can correctly identify individuals who are capable of performing firefighting work;
- When performing the same external work there is no difference in VO_2 for males and females.

6.3 Recommendations for Future Research

The findings from this research provide a basis for future investigations. The first study took a novel approach in identifying the cardiac responses of selected firefighter training; however, it was limited to single training days. Recently, Takeyama et al. (2005) revealed that 17 days of various firefighting shifts adversely affected autonomic nerve function as assessed by heart rate variability. Future study on the accumulated effect of repeated training days would be of interest as most courses are one week in duration and many fulltime firefighter programs are eleven weeks in total.

As described in Chapter 4, the effects of the SCBA and PPE on cardiorespiratory responses during exercise are fairly well understood in males. There are, however, no published reports describing the impact the SCBA or PPE has on females. Gonzales and Scheuermann (2006) recently demonstrated there may be gender differences associated fatigability of the inspiratory musculature, which may suggest the potential for gender differences when minute ventilations are greater than 100 $L{\bullet}min^{-1}$ while breathing from the SCBA.

In Chapter 5 we determined the average VO_2 required to perform the FF Test at the 8-min standard. It would be of interest to determine the muscular strength and endurance components required for successful performance on the FF Test. The constant workload treadmill test replicated the aerobic component of the FF Test. Although the constant workload test was able to accurately identify true-positives, with the small number of subjects who failed to meet the FF Test standard, it was unable to accurately determine true-negatives. Therefore further study should be undertaken to elucidate the ability of the constant workload treadmill test to identify true-negatives.

6.4 References

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APPENDIX A

PSYCHOPHYSICAL SCALES

Numeral Indicator	Descriptor
6	
7	very, very light
8	
9	very light
10	
11	fairly light
12	
13	somewhat hard
14	
15	hard
16	
17	very hard
18	
19	very, very hard
20	

Figure A-1. Rating of Perceived Exertion (RPE) scale.

Numeral Indicator	**Descriptor**
1	not aware of my breathing
2	
3	starting to breathe hard
4	
5	getting hard to breathe
6	
7	not getting enough air

Figure A-2. Perceived Respiratory Distress (PRD) scale.

Numeral Indicator	**Descriptor**
1	comfortable temperature
2	
3	starting to get hot
4	
5	I am hot
6	
7	I am very hot
8	
9	heat is unbearable

Figure A-3. Perceived Thermal Distress (PTD) scale.

APPENDIX B

SAMPLE HEART RATE RESPONSE

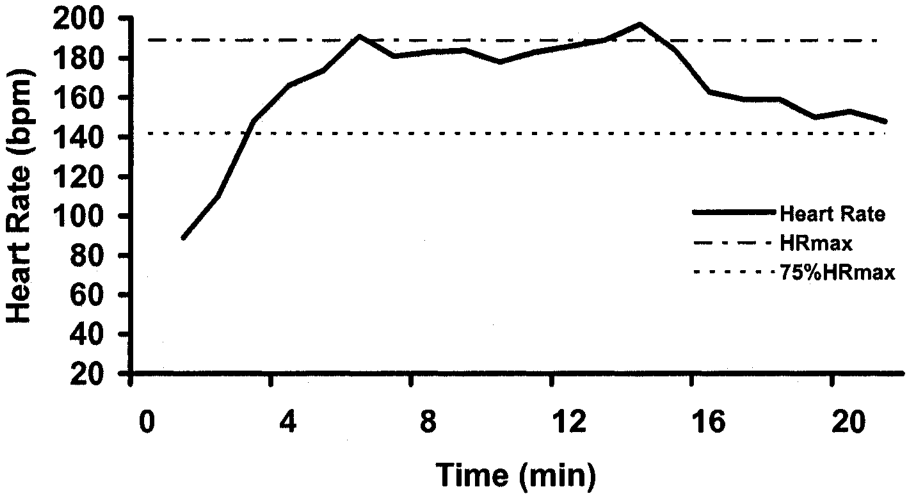

Figure B-1. Sample heart rate record from a student performing the "SCBA run". As described in Chapter 2.

APPENDIX C

EXPERIMENTAL APPRATUS

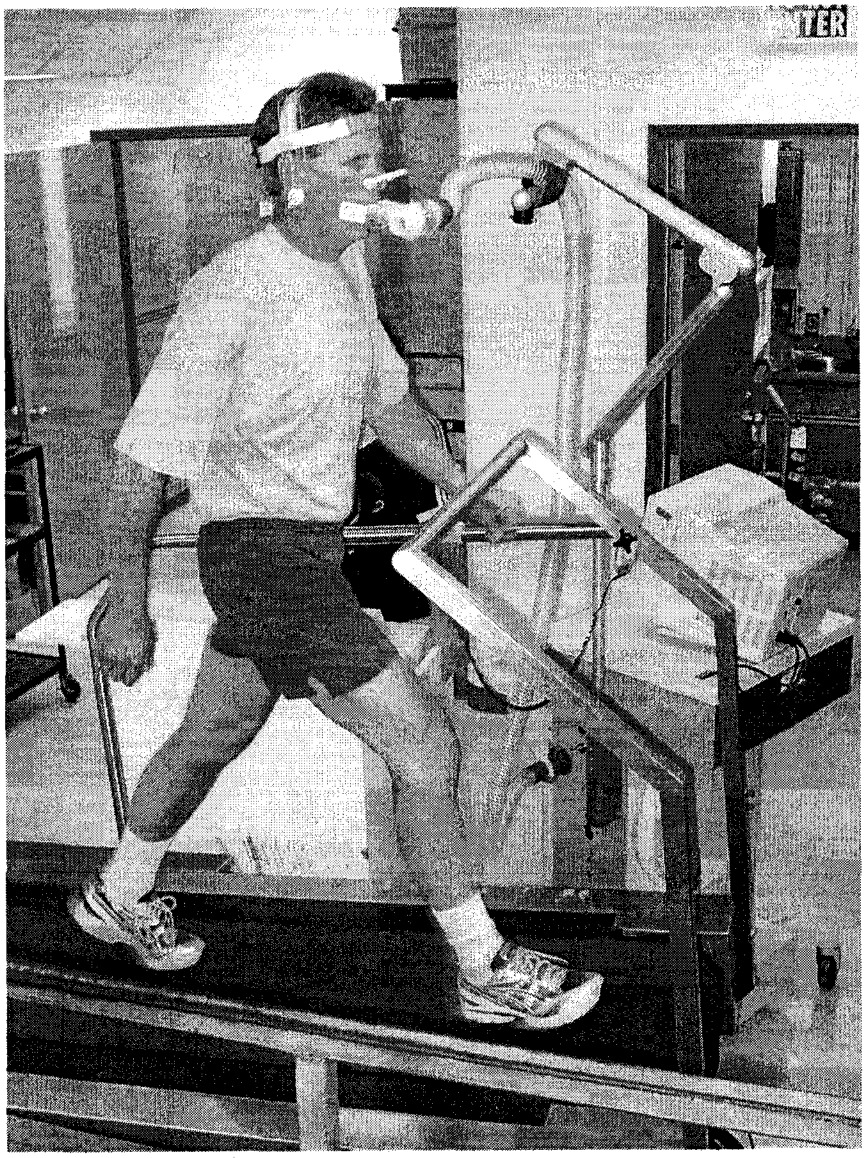

Figure C-1. Experimental set-up for the GXT_{PT} in Project Two (Chapter 4). Subjects wore typical exercise clothing while breathing through a low-resistance Hans Rudolph valve.

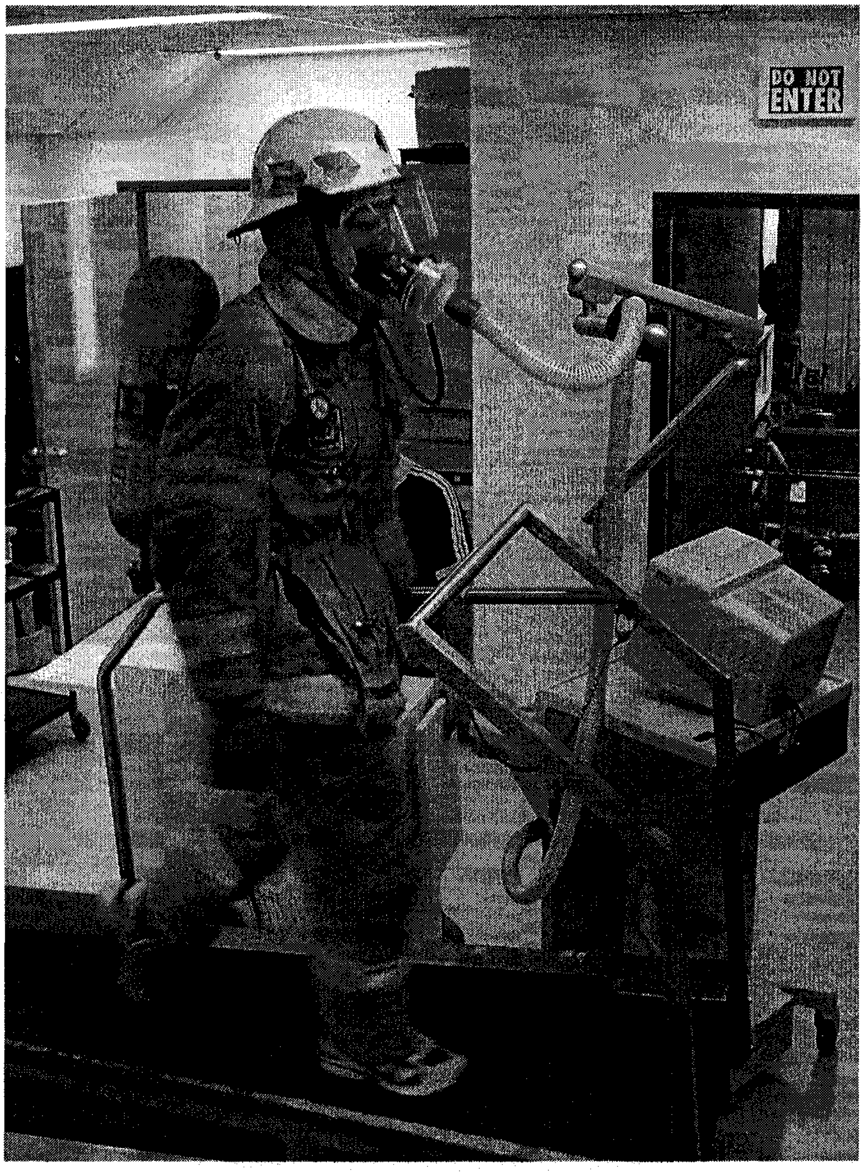

Figure C-2. Experimental set-up for the GXT_{PPE} in Project Two (Chapter 4). Subjects wore typical exercise clothing (Figure B-1) and full personal protective ensemble while breathing through an SCBA. Expired gases were collected via Plexiglass cone interfaced with the SCBA.

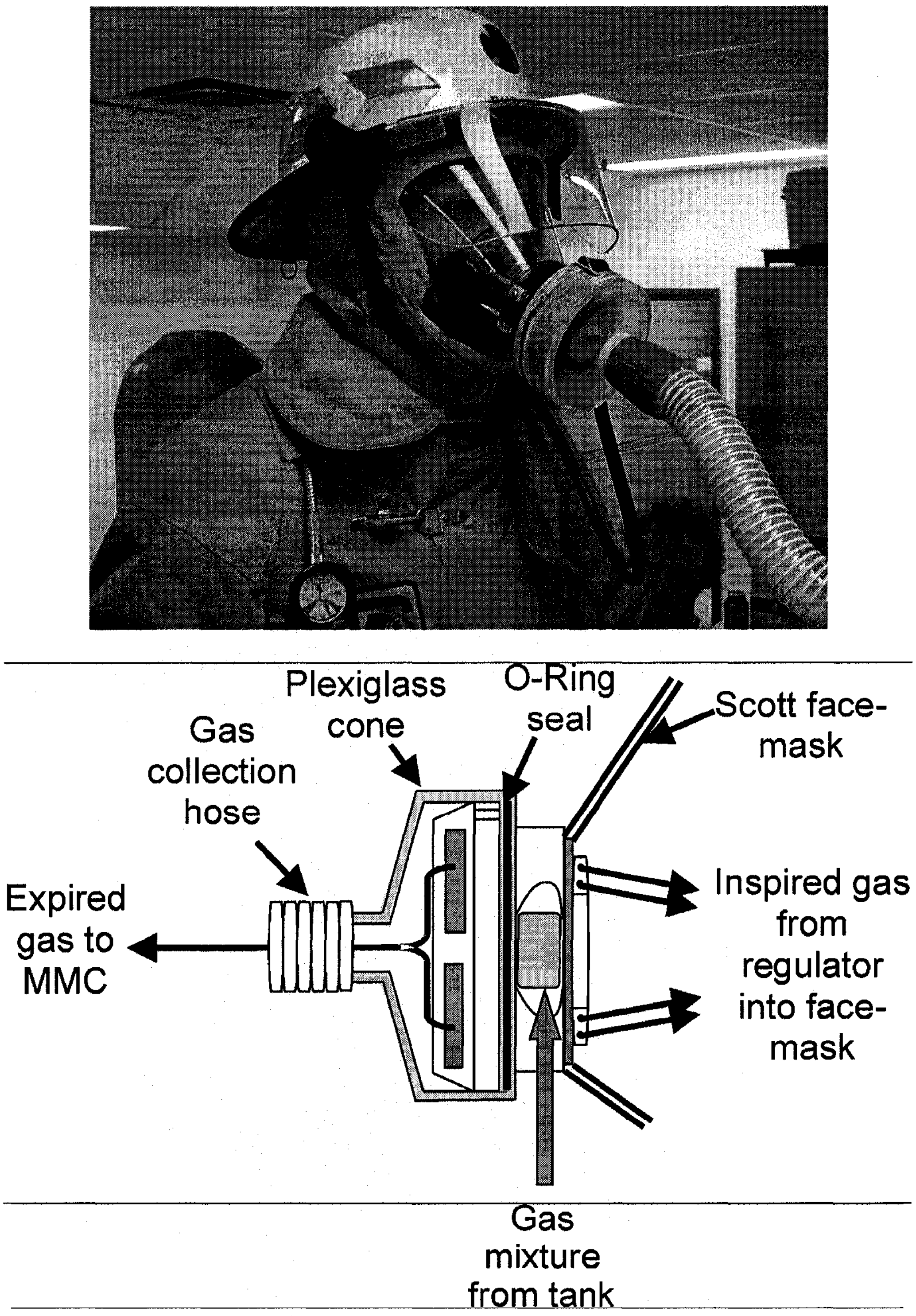

Figure C-3. Schematic of the regulator system and plexiglass cone.

From Eves et al. (2002).

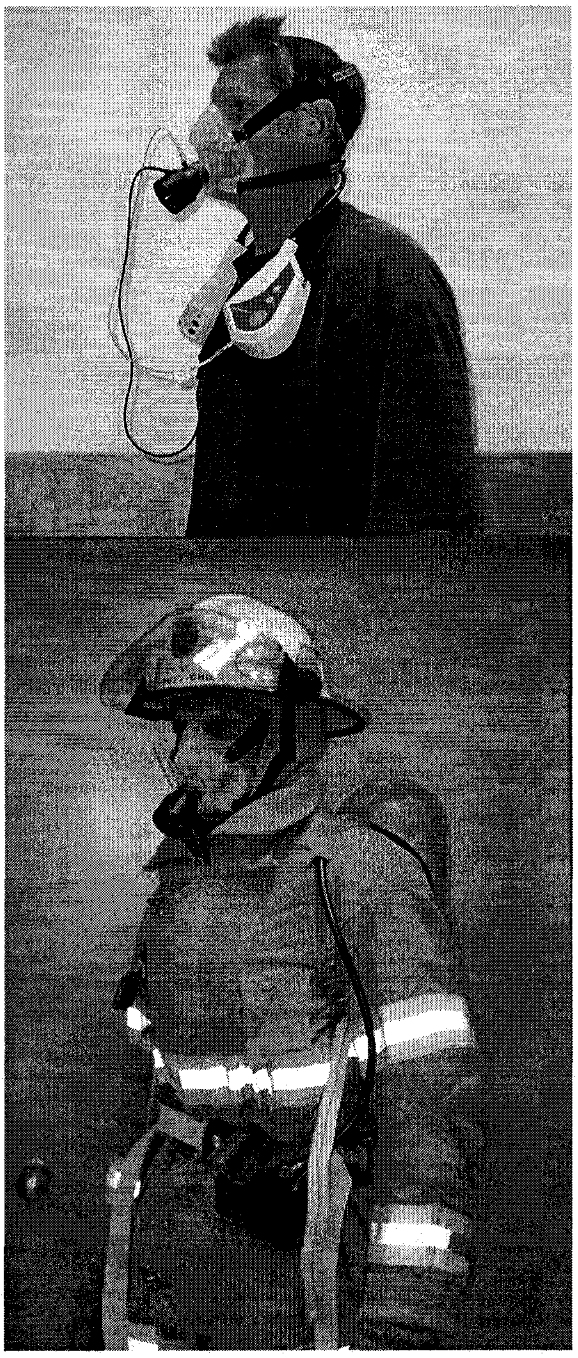

Figure C-4. Experimental set-up for MAX O_2 condition in Project Three (Chapter 5). Subjects wore typical exercise clothing (Figure B-1) and full personal protective ensemble while breathing through a Hans Rudolph full-face mask.

Figure C-5. Experimental set-up for GXT condition in Project Three (Chapter 5). Subjects wore typical exercise clothing (Figure B-1) and full personal protective ensemble while breathing through a Hans Rudolph full-face mask.

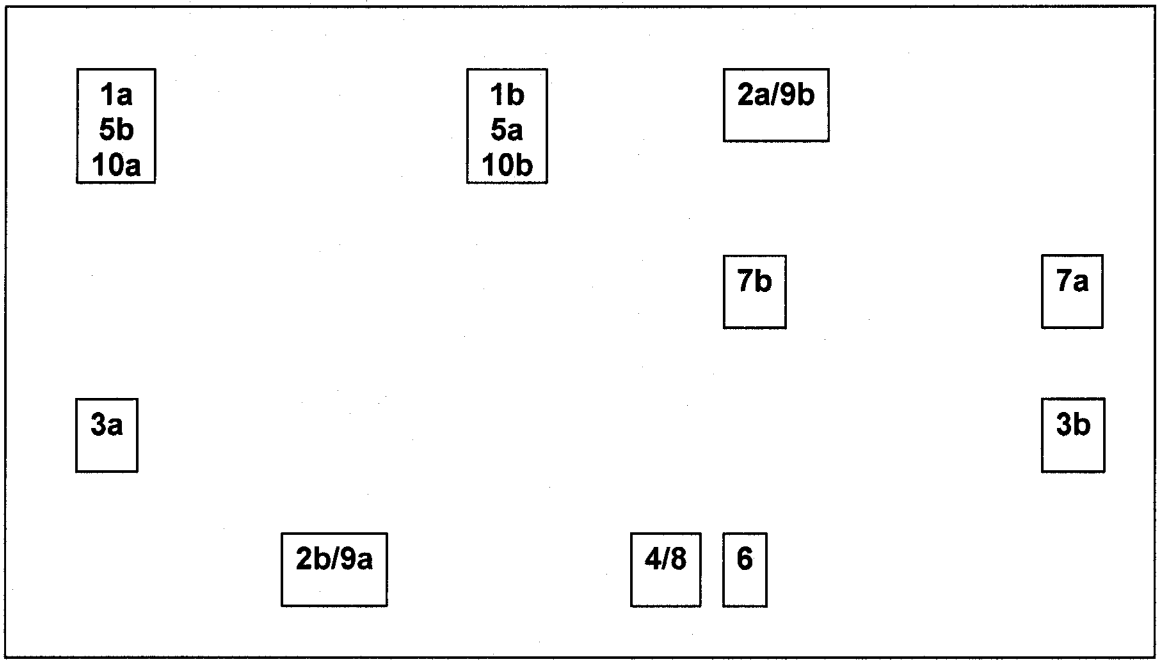

Figure C-6. Schematic of the FF Test from Project Three (Chapter 5).

1- Hose carry: a – start and end, b – transition point.
2- Ladder carry and raise: a – start, b – end.
3- Hose drag: a – start, b – end.
4- Ladder climb 1
5- Rope pull: a – start, b – end.
6- Forcible entry
7- Victim rescue: a – start and end, b – transition point.
8- Ladder climb 2
9- Ladder lower and carry: a – start, b – end.
10- Spreader tool carry: a – start and end, b – transition point.

APPENDIX D

ADDITIONAL STATISTICAL ANALYSIS

Coincidence Testing

In Project Three (Chapter 5), regression analysis was utilized to predict the value of a dependent variable (Y – averageVO_2) from a know independent variable (X – performance time on the FF Test) value, for both male and female subjects. Regression analysis produced the following equations from the male and female data sets:

Male: $\hat{y} = 57.952 - 2.572\,x$

Female: $\hat{y} = 52.089 - 2.35\,x$

However, it was of interest to determine to what extent the regression relationships differed between the groups (males and females), in particular, whether or not they differed at all. Comparison of the two regression lines (coincidence testing) was calculated using the technique described by Kleinbaum et al. (1998), which is schematically depicted in Figure D-1.

The process involved pooling the data to fit a single model. Although, it was possible to fit a model to each of the datasets to test the hypothesis using two separate models, tests for coincidence are not equivalent and the single model is generally preferred. Moreover, by pooling the two datasets, there are improvements in the estimates of the regression parameters and the common variances (Kleinbaum et al., 1998).

Figure D-2 represents the possible outcomes from comparing two regression lines. Figure D-2 A indicates equal slopes and intercepts. Figure D-2

B indicates equal slopes and unequal intercepts. Figure D-2 C indicates unequal slopes and equal intercepts. Figure D-2 D indicates unequal slopes and intercepts. If coincidence was shown, as represented in Figure D-2A, then a single regression equation would be most appropriate.

Utilizing the data from Table D-1, the following *F*-test statistic for coincidence was calculated:

$$F = \frac{(6.841 + 0.476)/2}{13.225} = 0.276.$$

This value was then compared with an *F* (3, 48)-distribution, the *p*-value was found to be greater than 0.05. Therefore, the combined model for the relationship between average VO_2 and performance time on the FF Test was $\hat{y} = 63.091 - 3.62\ x$, regardless of gender. Figure D-3 provides a graphical representation of the coincidence testing for the males, females, and the combined equation for the entire group.

Table D-1. ANOVA table for average VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$) from the MAX O_2 trial.

Source	*d.f.*	Sum of squares	Mean square	*F*-value	*p*-value
Gender	1	6.841	6.841	.517	.47
Time	1	234.709	234.709	17.747	.0001
Gender x Time	1	.476	.476	.036	.8503
Residual	48	634.807	13.225		

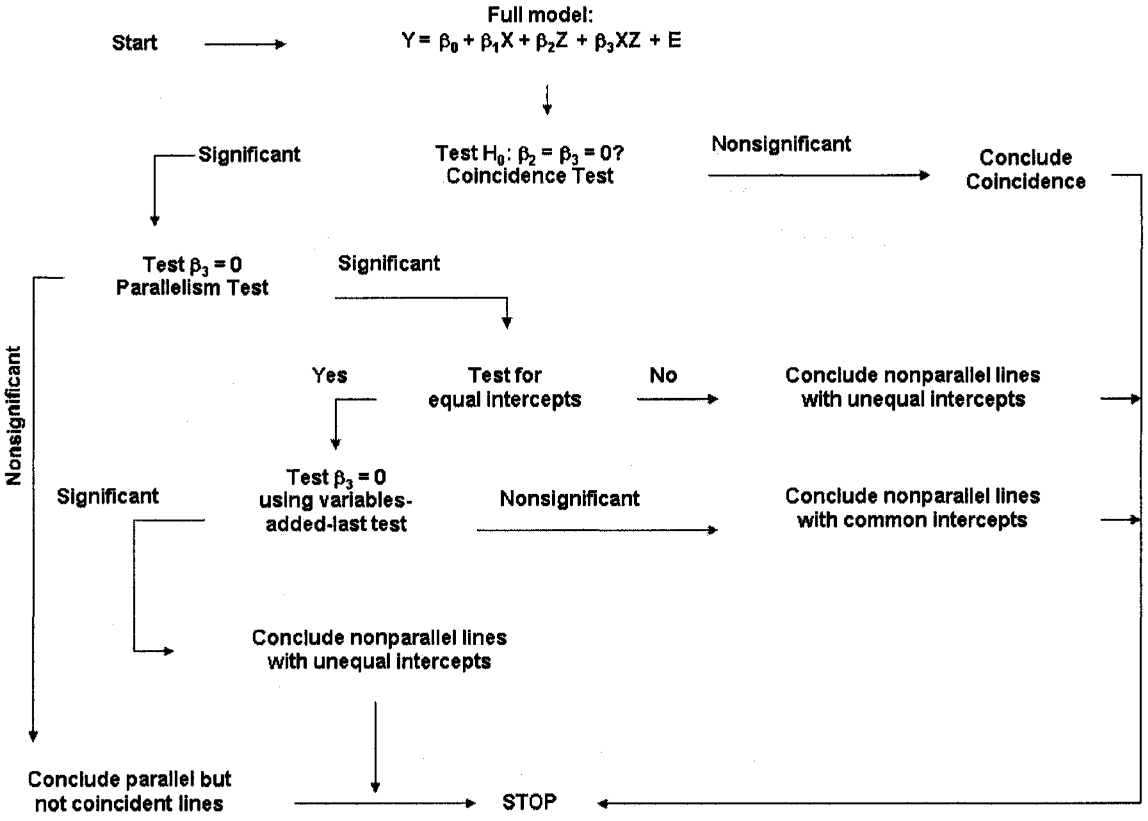

Figure D-1. Schematic representation of the process for comparing two regression lines. Adapted from Kleinbaum, Kupper, Muller, and Nizam (1998) Applied regression analysis and multivaribale methods.

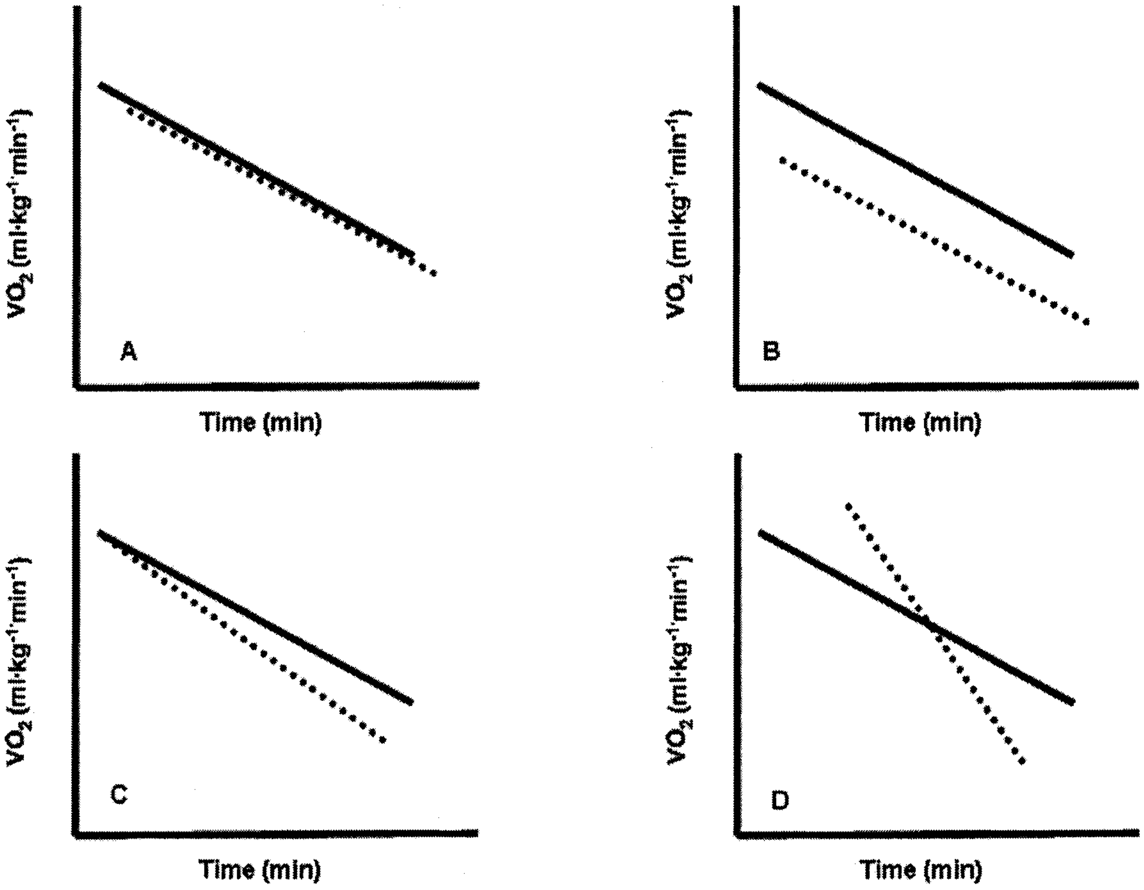

Figure D-2. Schematic representation of the possible conclusion from comparing two regression lines. A indicates equal slopes and intercepts. B indicates equal slopes and unequal intercepts. C indicates unequal slopes and equal intercepts. D indicates unequal slopes and intercepts. Adapted from Kleinbaum, Kupper, Muller, and Nizam (1998) Applied regression analysis and multivaribale methods.

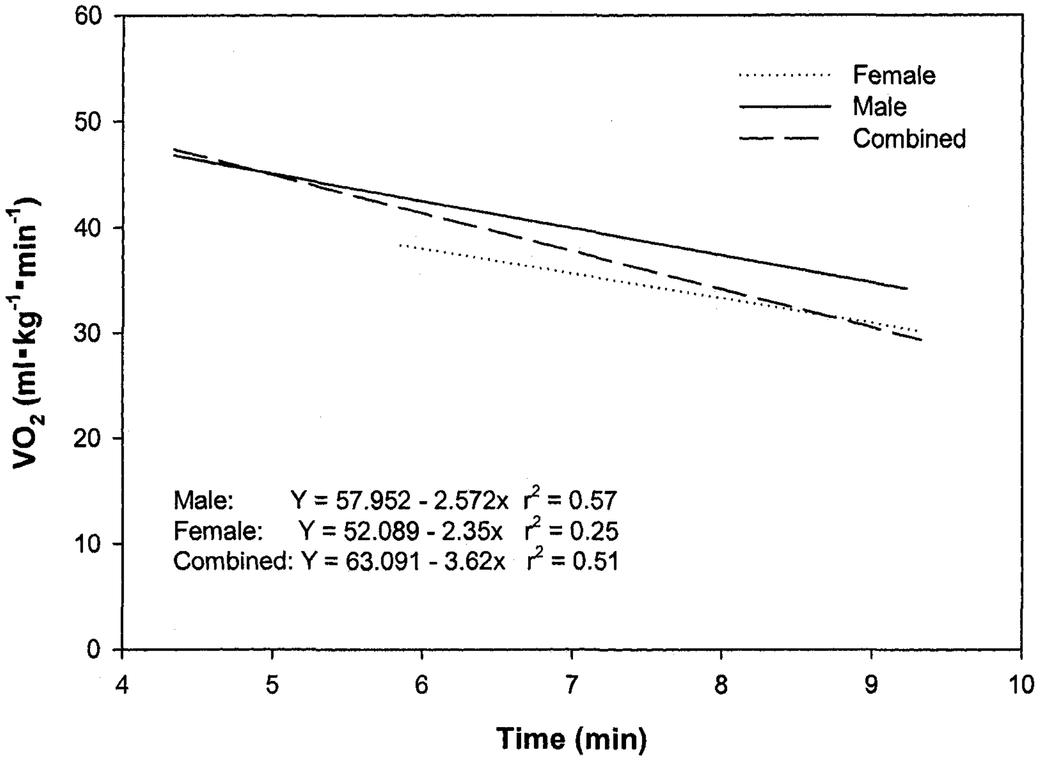

Figure D-3. Regression lines for the males, females, and combined group, from the data presented in Project Three (Chapter 5). Predicted VO_2 for males was 37.4 ml•kg^{-1}•min^{-1} when X = 8 min; females was 33.3 ml•kg^{-1}•min^{-1} when X = 8 min; and, combined was 34.1 ml•kg^{-1}•min^{-1} when X = 8 min.

Diagnostic Utilities

In project three (Chapter 5), diagnostic utilities analysis (Fletcher et al., 1988) was performed to assess the ability of VO_2max and the constant workload treadmill test to identify individuals able to complete the FF Test at or below the 8-min standard (Figure D-4). The specificity, sensitivity, positive predictive value, negative predictive value, and accuracy were calculated from the raw data as described in Figure D-4.

Figure D-5 depicts the diagnostic utilities results when the constant workload treadmill test was used as a cut-off. The cut-off was based on completing or not completing the 8-min treadmill exercise.

In order to calculate the diagnostic utilities for VO_2max, the value used in the analysis was based on averaging the recommended VO_2max values presented in the literature (O'Connell et al.,1986, 39 ml•kg^{-1}•min^{-1}; Sothmann et al., 1990, 33.5 ml•kg^{-1}•min^{-1}; Sothmann et al., 1992, 42 ml•kg^{-1}•min^{-1}; Gledhill and Jamnik, 1992b, 45 ml•kg^{-1}•min^{-1}; Bilzon et al., 2001, 41 ml•kg^{-1}•min^{-1}; NFPA, 2003, 42 ml•kg^{-1}•min^{-1}; von Heimberg et al., 2006, 48 ml•kg^{-1}•min^{-1}). The average value calculated from these sources was 41 ml•kg^{-1}•min^{-1}. Figure D-6 depicts the number of cases that were identified as true-positive, false-positive, false-negative or true-negative when a VO_2max cut-off value of 41 ml•kg^{-1}•min^{-1}.

For comparative purposes diagnostic utilities were calculated when VO_2max was set at the highest (Figure D-7) and lowest (Figure D-8) recommend value from the literature.

		Performance time on the FF Test	
		≤ 8-min	> 8-min
Treadmill test results	VO_2max Or CW treadmill test	True Positive a	b False Positive
	VO_2max Or CW treadmill test	c False Negative	d True Negative

Sensitivity = $\frac{a}{a+c}$

Specificity = $\frac{d}{b+d}$

Positive predictive value = $\frac{a}{a+b}$

Negative predictive value = $\frac{d}{c+d}$

Accuracy = $\frac{a + d}{a+b+c+d}$

Figure D-4. The relationship between laboratory test results (e.g., VO_2max or constant workload, CW) and FF Test performance (≤ 8-min or > 8-min).

		Performance time on the FF Test	
		≤ 8-min	> 8-min
CW phase treadmill test	Complete	47	5
	Incomplete	0	0

		Performance time on the FF Test	
		≤ 8-min	> 8-min
CW phase treadmill test	Complete	28	1
	Incomplete	0	0

		Performance time on the FF Test	
		≤ 8-min	> 8-min
CW phase treadmill test	Complete	19	4
	Incomplete	0	0

Figure D-5. Accuracy of constant workload treadmill test completion to correctly categorize individual FF Test performance time. Results for the overall group, males and females are found in the top-, middle- and bottom-panel, respectively.

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 41 ml•kg^{-1}•min^{-1}	36	2
	< 41 ml•kg^{-1}•min^{-1}	11	3

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 41 ml•kg^{-1}•min^{-1}	26	1
	< 41 ml•kg^{-1}•min^{-1}	2	0

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 41 ml•kg^{-1}•min^{-1}	10	1
	< 41 ml•kg^{-1}•min^{-1}	9	3

Figure D-6. Accuracy of VO$_2$max (41 ml•kg^{-1}•min^{-1}) to correctly categorize individual FF Test performance (≤ 8-min and > 8-min). Results for the entire group, males and females are found in the top-, middle- and bottom-panel, respectively.

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 48 ml•kg^{-1}•min^{-1}	20	0
	< 48 ml•kg^{-1}•min^{-1}	27	4

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 48 ml•kg^{-1}•min^{-1}	17	0
	< 48 ml•kg^{-1}•min^{-1}	11	1

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 48 ml•kg^{-1}•min^{-1}	3	0
	< 48 ml•kg^{-1}•min^{-1}	16	3

Figure D-7. Accuracy of VO$_2$max (48.0 ml•kg^{-1}•min^{-1}) to correctly categorize individual FF Test performance (≤ 8-min and > 8-min). Results for the entire group, males and females are found in the top-, middle- and bottom-panel, respectively.

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 33.5 ml•kg^{-1}•min^{-1}	47	4
	< 33.5 ml•kg^{-1}•min^{-1}	0	1

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 33.5 ml•kg^{-1}•min^{-1}	28	1
	< 33.5 ml•kg^{-1}•min^{-1}	0	0

		Performance time on the FF Test	
		≤ 8-min	> 8-min
VO$_2$max value from the GXT	≥ 33.5 ml•kg^{-1}•min^{-1}	19	3
	< 33.5 ml•kg^{-1}•min^{-1}	0	1

Figure D-8. Accuracy of VO$_2$max (33.5 ml•kg^{-1}•min^{-1}) to correctly categorize individual FF Test performance (≤ 8-min and > 8-min). Results for the entire group, males and females are found in the top-, middle- and bottom-panel, respectively.