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CARDIOVASCULAR DISEASE RISK FACTORS IN STRUCTURAL FIREFIGHTERS

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Nicholas W. Trubee, Student

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CARDIOVASCULAR DISEASE RISK FACTORS IN STRUCTURAL FIREFIGHTERS

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Education at the University of Kentucky

BY

Nicholas William Trubee

Lexington, KY

Director: Dr. Mark Abel, Associate Professor of Exercise Physiology

Lexington, KY

2015

ABSTRACT OF DISSERTATION

CARDIOVASCULAR DISEASE RISK FACTORS IN STRUCTURAL FIREFIGHTERS

This dissertation is composed of two manuscripts assessing cardiovascular disease (CVD) risk in structural firefighters. Study 1 compared traditional CVD risk factors and health-related behaviors between professional and volunteer firefighters. Online questionnaires were sent to approximately 4000 firefighters in the state of Kentucky. The results indicated that 90% of volunteer and 58% of professional firefighters were classified as moderate-to-high CVD risk. Volunteer firefighters were significantly ($p < 0.001$) older and more likely ($p = 0.026$) to be current cigarette smokers. The mean body mass index among all firefighters in the sample was $30.8\ kg \cdot m^{-2}$. Nearly 60% of volunteer firefighters were obese. Obese firefighters were more likely ($p < 0.05$) to have been diagnosed as diabetic or pre-diabetes compared to overweight and normal weight firefighters. These results indicate that volunteer firefighters may be at a greater CVD risk compared to professional firefighters.

Study 2 investigated the association of cardiorespiratory fitness (CRF) and body fat with arterial stiffness in professional firefighters. Forty-six male professional structural firefighters performed a maximal graded exercise test in personal protective equipment and noninvasive arterial stiffness assessments before and for 60 minutes post-exercise. Percent body fat was measured with a bioelectrical impedance analyzer. Firefighters were stratified into fit ($VO_{2peak} \geq 48.3\ ml \cdot kg^{-1} \cdot min^{-1}$) and unfit ($VO_{2peak} < 48.3\ ml \cdot kg^{-1} \cdot min^{-1}$) groups. Pulse wave velocity, an indicator of arterial stiffness, was significantly lower overall in the fit group compared to the unfit group ($p < 0.001$). However, the fit group had significantly less relative body fat compared to the unfit group. Thus, when controlling for the confounding effects of fatness, the results indicated that there was a significant effect of relative body fat ($p < 0.001$) but no effect of fitness on arterial stiffness ($p = 0.490$). This indicated that relative body fat was responsible for the difference in arterial stiffness and not the fitness stratification. The unfit group displayed a significantly higher average carotid-femoral pulse wave velocity of $1.004\ m \cdot s^{-1}$ which may increase the risk of a sudden cardiac event by 14%. In addition, there was no main effect for time ($p = 0.794$) or group x time interaction ($p = 0.906$). Most resting measures of central and brachial pressure were significantly higher in the unfit group.

Results from this dissertation indicated that volunteer firefighters have a greater CVD risk than professional firefighters. Furthermore, relative body fat has a greater effect on arterial stiffness than cardiorespiratory fitness. Collectively, these findings indicate the need for innovative weight management strategies to decrease CVD risk among structural firefighters.

KEYWORDS: Carotid-femoral pulse wave velocity (cfPWV)
Cardiorespiratory fitness (CRF)
Cardiovascular disease (CVD)
Personal Protective Equipment (PPE)

Nicholas W. Trubee

(Author's Signature)

July 28, 2015

(Date)

CARDIOVASCULAR DISEASE RISK FACTORS IN STRUCTURAL FIREFIGHTERS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

DISSERTATION INTRODUCTION

The research presented in the following chapters represents work conducted by the primary author and investigator in order to satisfy the requirements for completion of a Ph.D. in Exercise Physiology from the University of Kentucky. These guidelines were set forth and reviewed by the Graduate School and members of the Dissertation Committee. The dissertation is presented in chapter format in an effort to present an organized research report. A detailed literature review summarizing the current evidence in cardiovascular disease risk (CVD) factors and health-related behaviors comprises the second chapter. Chapter three includes a completed research manuscript comparing CVD risk factors between volunteer and professional firefighters. Chapter four includes a completed research manuscript describing the effect of cardiorespiratory fitness and body fat on arterial stiffness in professional firefighters. Finally, Chapter five presents a brief, integrated conclusion based on the analysis of the results from both studies.

Study one compared traditional CVD risk factors and health-related behaviors between 175 professional and volunteer firefighters in the state of Kentucky. Cardiovascular disease represents the most common type of fatality in the fire service, accounting for 42% of all firefighter fatalities in the last 5 years (34). Additionally, evidence indicates that the majority of CVD deaths are occurring in volunteer firefighters (35). Therefore, our initial hypothesis suggested that the prevalence of CVD risk factors among volunteer firefighters would be greater than professional firefighters. We further hypothesized that the majority of firefighters would be classified as moderate-to-high

CVD risk and have a greater prevalence for obesity compared to state and national populations.

The results of study one directed the design for the second research project. As the information gained from study one was subjective and self-reported, we utilized an objective assessment of CVD risk by measuring arterial stiffness via carotid-femoral pulse wave velocity (cfPWV). As physical fitness plays a major role in the firefighting profession, we evaluated the association of cardiorespiratory fitness (CRF) with arterial stiffness. Previous research has displayed an inverse relationship between cardiorespiratory fitness and cfPWV, suggesting that elevated fitness results in decreased arterial stiffness (20, 40, 106). A decrease in arterial stiffness due to increased physical activity and fitness may reduce CVD risk and the likelihood of experiencing a cardiovascular event and cardiovascular mortality, respectively (109).

Forty-six professional structural firefighters ranging in age from 22-50 years from a City fire department volunteered to partake in the investigation. We hypothesized that the leaner fit group of firefighters would have less arterial stiffness than the fatter unfit group of firefighters at rest and up to 60 minutes post-exercise.

Our results provide further evidence to support the established trends of CVD risk among firefighters. Specifically, firefighters demonstrated elevated traditional and objective measures of CVD risk, respectively. Further research is warranted on other factors that may elevate CVD risk among firefighters such as objective measures of sleep patterns, physical activity, and dietary habits.

CHAPTER II
REVIEW OF LITERATURE

Introduction

Firefighting is a hazardous and strenuous occupation. However, many firefighters possess elevated cardiovascular disease (CVD) risk profiles (41, 49, 98) posing an increased threat to those on-duty and the surrounding community. The primary cause of on-duty fatalities in the fire service is sudden cardiac death (32, 33, 34, 35). Fahy et al. (33) defined sudden cardiac death as "the sudden, abrupt loss of heart function in a person who may or may not have diagnosed heart disease." Fatality rates occurring in firefighters reported from the previous decade show that 1,006 firefighters died in the line of duty, where 440 of those deaths were due to sudden cardiac death. The term "on-duty" refers to many tasks, including: responding to or return from an alarm, being on the scene of an alarm of a fire or non-fire related incident, while participating in other fire department duties such as training, maintenance, public education, inspection, investigation, court testimony or fund raising, and being on call or stand-by for assignment at a location other than at the firefighter's home of place of business (36).

Cardiovascular disease among the fire service

Current research on the health and well-being of those in the fire service has shown that many possess an elevated risk for CVD (41, 49, 98). When assessing CVD among the fire service, the use of the American College of Sports Medicine (ACSM) (1) CVD risk stratification is frequently employed. According to the ACSM, there are eight positive risk factors for cardiovascular disease, including: (1) age (men ≥ 45 years; women ≥ 55 years), (2) family history (myocardial infarction or sudden death in immediate family before 55 years of age in father or other male first-degree relative, or before 65 years of age in mother or other female first-degree relative), (3) cigarette smoking (current smoker, those who have quit in the past six months), (4) obesity (BMI ≥ 30 $kg \cdot m^{-2}$), (5) hypertension (systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥ 90 mmHg), (6) dyslipidemia (total cholesterol ≥ 200 $mg \cdot dL^{-1}$), (7) pre-diabetes (fasting glucose ≥ 100 $mg \cdot dL^{-1}$ and < 126 $mg \cdot dL^{-1}$), (8) and sedentary lifestyle (< 30 minutes of moderate intensity physical activity on at least 3 $d \cdot wk^{-1}$ for at least three months). Positive risk factors can then be summed in order to stratify risk and categorized as low, moderate, or high. CVD risk stratification is identified as follows: Low risk: asymptomatic with ≤1 CVD risk factor; Moderate risk: asymptomatic with ≥2 cardiovascular risk factors; High risk: known cardiovascular, metabolic or pulmonary disease or with ≥1 signs or symptoms of cardiovascular, metabolic or pulmonary disease (i.e., pain, discomfort in the chest or other areas that may result from ischemia, shortness of breath at rest or with mild exertion, dizziness or syncope, orthopnea or paroxysmal nocturnal dyspnea, ankle edema, palpitations or tachycardia, intermittent claudication, known heart murmur, unusual fatigue or shortness of breath with usual activities).

Previous investigations examining fatality rates among the fire service have shown that deaths due to CVD range from 30 to 49% of total on-duty deaths that occur each year (33, 34, 35). Many of the post mortem reports from those firefighters who died from sudden cardiac death showed that many had prior heart attacks, diagnosed and undiagnosed severe arteriosclerotic heart disease, diabetes, hypertension, hypercholesterolemia, considered obese, had family history of heart disease, and were current cigarette smokers. A majority of the on-duty sudden cardiac deaths have occurred while performing firefighting related tasks and drills. Fahy (32) reported that many of these deaths occurred during ladder climbing, pumping and drafting operations, SCBA (self-contained breathing apparatus) and smoke drills, as well as, during physical fitness training (running and resistance training). Of the fatalities that occurred during physical fitness training, nearly all of the firefighters had significant health problems, such as previous myocardial infarction, bypass or surgery/stent operation, or diagnosed and undiagnosed arteriosclerotic heart disease (occlusion of at least 50%) (32, 33).

In 2013, 29 firefighter deaths in the United States were classified as sudden cardiac death/myocardial infarction, accounting for the largest number of firefighter fatalities that year (34). Additionally, in 2010, 34 firefighter fatalities were classified as sudden cardiac deaths and many of these firefighters had elevated CVD risk profiles (35). A recent CVD risk factor screening was performed on a large pool of nearly 8,000 United States firefighters. The screening revealed that 37% were diagnosed with hypercholesterolemia (total cholesterol ≥ 200 mg/dl), 48% were diagnosed as being pre-hypertensive (120-139 mmHg systolic and/or 80-89 mmHg diastolic), 37% were diagnosed with stage 1 hypertension (140-159 mmHg systolic or 90-99 mmHg diastolic), 6.2% were diagnosed with stage 2 hypertension (≥160 mmHg systolic or ≥100 mmHg diastolic), while only 16.9% were classified as having normal blood pressure (<120 mmHg systolic and <80 mmHg diastolic) (35). An additional health screening of over 2000 firefighters showed that 44.7% were obese (Body Mass Index > 30 $kg \cdot m^{-2}$, or ≥ 25% body fat for men and ≥32% body fat for women) (35). Furthermore, a third screening was performed on 1650 firefighters resulting in nearly 50% of the firefighters screened as having high overall coronary risk rating according to the NIH "National Cholesterol Education Program" (35).

Kales and coworkers (48) examined 52 male firefighters who died while on-duty and determined that most of the deaths due to CVD occurred during fire suppression, training, and responding to an alarm. The risk profiles of the firefighters who died in this investigation were compared to a control group of 310 healthy male firefighters and found that those who died due to CVD had significantly higher prevalence of smoking, hypertension, had previously diagnosed arterial occlusive disease, and were older. The main finding from this study was that the fatalities due to CVD occurred in firefighters with underlying coronary artery disease. As age is highly associated with an elevated risk for CVD related events, Yang et al. (116) investigated sudden cardiac deaths among firefighters who were younger than 45 years of age. These firefighters had one fewer positive risk factor for CVD corresponding to the age threshold of 45 years of age (1). However, the younger victims examined in this investigation were still considered high risk as 63% were classified as obese (Body mass index >30 $kg \cdot m^{-2}$) and many others were hypertensive. Furthermore, the risk for sudden cardiac death increased 12-fold for those who were hypertensive and had left ventricular hypertrophy, likely due to chronic high blood pressure (116).

Furthermore, investigations by Scanlon et al. (87) and Yoo et al. (118) collected self-reported data concerning CVD risk profiles in volunteer firefighters. These studies found that greater than 75% of responders were considered overweight or obese. Many survey responders were also classified as hypertensive and exhibited altered blood lipid profiles. Yoo et al. (118) also found that the prevalence of overweight and obesity, as well as, tobacco usage among the responding firefighters, was higher than those of the general population.

Section I: Cardiovascular Disease Risk Factors and Associated Behaviors

The role of physical activity on cardiovascular disease risk

According to the American College of Sports Medicine (1), a sedentary lifestyle is a positive risk factor for CVD and is defined as not participating in at least 30 minutes of moderate intensity (40%-60% VO_2 reserve) physical activity on at least three days per week for at least three months. Many studies have investigated the relationship between physical activity and CVD risk among an adult population (9, 23, 40) as well as among the firefighting population using both objective (40) and subjective (23, 91, 103) measures. The means for measuring physical activity in these investigations was done objectively with the use of tri-axial accelerometers and subjectively by questionnaire/survey tools.

Talbot and coworkers (103) utilized a longitudinal study design in an attempt to compare physical activity and risk of coronary events in adult men. The subjects included in this investigation were male volunteers from the Baltimore Longitudinal Study of Aging. A total of 522 healthy younger ($\leq$ 65 years of age) and 167 older (> 65 years of age) men were included in the study, where the mean follow-up time between visits was 13.4 ± 6.3 years. All measures of leisure time physical activity were self-reported via survey where subjects selected time spent in 97 different activities. The time spent during these activities was then converted into MET-minutes per 24 hours (Metabolic equivalent = $3.5\ ml \cdot kg^{-1} \cdot min^{-1}$). The subjects were then grouped into categories dependent on the intensity of their daily leisure time physical activity and classified as high ($\geq$ 6 METs), moderate (4 to 5.9 METs), and low intensity (< 4 METs). When predicting coronary events among the younger and older groups based off leisure time physical activity, results were dependent on age and intensity of physical activity performed. In the younger cohort, leisure time physical activity among low, moderate, and high groups was not able to show a reduced risk of CVD. However, when assessing this relationship in the older groups, those categorized in the high intensity leisure time physical activity group showed a reduction of coronary risk, providing evidence that participating in physical activity may be advantageous in reducing CVD risk.

A second study performed by Gando et al. (40) investigated the relationship between physical activity time and CVD risk. This investigation included 538 healthy adult men (n=172) and women (n=366) categorized into young (< 40 years of age), middle-aged (40 to 59 years of age), and older (>60 years of age) age groups. The duration and intensity of physical activity performed by the subjects were objectively measured for 14 days with the use of a tri-axial accelerometer (Actimarker EW4800, Panasonic Electric Works). Among the three groups, there was no difference in time spent in moderate intensity physical activity. However, daily time spent in vigorous physical activity was shorter in the middle-aged and older age groups compared to the young age group. The key findings in the investigation were that longer amount of time spent in light physical activity, especially in older unfit adults, was associated with a reduced CVD risk.

A third study relating physical activity and CVD risk was performed in on-duty firefighters (23). This study employed a cross sectional design with 527 firefighters (37.2 ± 8.6 years of age) where physical activity intensity, frequency, and duration were estimated using self-reported data from health and lifestyle questionnaires. Measures of CVD risk factors such as body mass index (obesity), blood pressure, and blood lipid profiles (total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, and glucose) were also assessed. When assessing physical activity frequency, nearly 75% of the subjects failed to engage in the minimum requirement of 150 minutes of aerobic exercise on a weekly basis for cardiovascular health (1, 13). However, frequency of physical activity was found to be strongly associated with both positive and negative CVD risk factors such as a reduction in total cholesterol and an increase in HDL cholesterol, respectively. Therefore, the key finding in this investigation was that increasing exercise frequency in the firefighter sample produced the most beneficial effects on CVD risk factors.

The role of physical fitness on cardiovascular disease risk

Physical fitness plays a vital role as it pertains to everyday firefighting tasks and duties. A training program that encompasses strength, power, muscular endurance, and cardiorespiratory fitness is essential in the field of duty. Rhea and colleagues (83) examined the relationship between many fitness parameters and job performance and ultimately determined that cardiovascular endurance, anaerobic endurance, muscular strength, and local muscular endurance are needed in order to be a productive member of a firefighting battalion. Amongst the literature, many investigations have assessed the relationship between cardiorespiratory fitness and CVD risk factors among on-duty firefighters (4, 21, 23, 80). For example, Baur and associates (4) performed a cross sectional study involving 968 male firefighters (39.5 ± 8.6 years of age) in an attempt to predict CVD risk based on cardiorespiratory fitness. Cardiorespiratory fitness was estimated via the Bruce or modified Bruce treadmill protocol. CVD risk factors such as obesity (body mass index), resting blood pressure, and blood lipid profiles were also collected. The minimum required fitness standard suggested by the National Fire Protection Association (NFPA) (70) is 12 METs (42.0 mLkg^{-1}min^{-1}). The mean fitness level of the firefighters included in this study was 12.0 METs (±1.9), however, 44% had a cardiorespiratory fitness of less than the 12 MET minimum requirement. In terms of CVD risk, significant associations were seen between increased fitness levels and reduced CVD risk. These include favorable alterations in blood lipid profiles such as increased HDL cholesterol and reduced LDL cholesterol. Furthermore, increased levels of fitness were significantly associated with a reduction in body mass index.

Donovan et al. (21) and Poston et al. (80) also examined the role of cardiorespiratory fitness in firefighter health and job performance. These two investigations found that as high as 60% of the firefighters assessed did not meet or exceed the aforementioned minimum fitness level needed for firefighting duties. These two investigations also found that 75% of all firefighters examined were considered overweight or obese. When taking into account obesity on cardiorespiratory fitness, nearly three quarters of the normal weight firefighters met or exceeded the 42 ml·kg^{-1}·min^{-1} recommendation, however, 80% of the obese career firefighters did not meet the minimum standard.

Among the general adult population, the same inverse relationship exists between cardiorespiratory fitness and CVD risk as presented among career firefighters. Kodama and coworkers (52) sought to investigate how fitness may be used as a quantitative predictor for CVD events in healthy adults. This study used a meta-analysis design in an attempt to increase predictability of CVD events relating to cardiorespiratory fitness from a large sample of subjects. In total, more than 100,000 subjects whose cardiorespiratory fitness had been estimated from a submaximal graded exercise test were analyzed. From these data, groups were formed as low fitness (<7.9 METs – 10.8 METs) and high fitness (≥10.9 METs). From the analysis, the authors found that an increase in 1 MET of maximal aerobic capacity was associated with 15% decrease in CVD. Furthermore, the same increase in aerobic capacity was also associated with a decreased waist circumference, lower resting blood pressure, and improved lipid profile and fasting glucose measurements. Overall, those who were in the low fitness group had higher rates of CVD and all-cause mortality compared to those whose cardiorespiratory fitness was above 7.9 METS.

Additionally, results from the study performed by Talbot et al. (103) found that in both younger (≤65 years of age) and older (>65 years of age) adults, higher levels of cardiorespiratory fitness were associated with a reduced risk of coronary heart disease. These data related leisure time physical activity to the aerobic capacity associated with those activities. Those performing ≥ 6 METs of leisure time physical activity on a regular weekly basis saw reduced risk for CVD compared to those in the moderate intensity (4 to 5.9 METs) and low intensity (<4 METs) activity groups.

Furthermore, improving cardiorespiratory fitness in adults has shown to mitigate vascular damage and in some cases show signs of improved vascular health (9, 20, 106). An inverse relationship has been displayed between vascular health and increased cardiopulmonary fitness, suggesting that interventions geared towards improving fitness may be beneficial in reducing risk of CVD.

When measuring cardiovascular fitness in firefighters, indirect calorimetry may be the most accurate assessment tool. Indirect calorimetry performed via metabolic cart uses measures of oxygen consumption as a means to estimate energy expenditure. Oxygen consumption (VO_2) is the amount of oxygen consumed and utilized for energy production. VO_2 is usually measured in liters per minute ($L \cdot min^{-1}$), however this measure may also be expressed in milliliters per kilogram per minute ($ml \cdot kg^{-1} \cdot min^{-1}$) to reduce the impact of body weight (larger individuals tend to consume more oxygen compared to smaller individuals).

When resources are sparse or the environment is not conducive, oxygen consumption can also be affectively estimated by the use of submaximal testing (104). Submaximal VO_2 testing utilizes the relationship between heart rate and oxygen consumption versus work rate to predict maximal oxygen uptake. The Gerkin submaximal graded exercise protocol has been utilized in many firefighting populations as a means to assess cardiorespiratory fitness. This protocol has been validated among a group of adult male and female firefighters (104). Cardiorespiratory fitness is based off the time to reach 85% of maximal heart rate and is entered into a firefighter-specific prediction equation to predict peak oxygen consumption (VO_{2peak}; $R^2 = 0.328$; Standard error of estimate = $5.20\ ml \cdot kg^{-1} \cdot min^{-1}$). Although the standard error of the prediction may seem high, Tierney and coworkers (104) found that the protocol tended to under-predict fitness levels and was able to separate those who were fit from those who were unfit. The authors suggested that the under prediction of cardiorespiratory fitness with the use of this protocol may alleviate overexertion injuries and deaths as opposed to an over prediction of VO_2. Additionally, Nord et al. (71) evaluated a revised version of the Fire

Service Joint Management Wellness-Fitness Initiative's (38) submaximal treadmill protocol in 83 professional firefighters. The results from this study found no difference ($p \leq 0.76$) in the predictive submaximal protocol from the measured maximal treadmill protocol (Estimated METs: 12.64 METs; Measured METs: 12.58 METs). These two investigations provide insight regarding the importance of selecting an appropriate fitness prediction protocol as an over estimation of cardiorespiratory fitness may lead to firefighters who should be deemed unfit into fire ground situations where they may not be able to successfully complete the task, leading to an increased risk for injury or fatality.

The role of obesity on cardiovascular disease risk

According to the Centers of Disease Control (12) and the American College of Sports Medicine (1), overweight is defined as a body mass index (BMI - body weight in kilograms divided by body height in meters squared) ranging between 25.0 $kg \cdot m^{-2}$ – 29.99 $kg \cdot m^{-2}$. In addition, obesity is categorized by a BMI greater than or equal to 30.0 $kg \cdot m^{-2}$. In terms of disease risk, obesity is considered a positive risk factor for CVD according to the ACSM (1). Also, a percent body fat of greater than 25% in adult males is classified as obese (80, 97). The use of BMI as a measurement of body composition can be misleading especially if used in an athletic population. Athletes with increased body weight due to large quantities of lean and fat-free mass, and low measures of fat mass, would be classified as obese according to BMI. However, when assessing body composition in the firefighting population, it was more likely that a firefighter would be classified as obese by percent fat than by BMI (80, 97). Thus, utilizing BMI as a measure of obesity in the firefighting population is appropriate and may even give a conservative estimate of body composition.

Among the firefighting population, the prevalence of overweight and obesity is becoming an increasing concern. According to many investigations, firefighters who are considered overweight or obese are greater than the proportion of average adults in the United States (35, 72, 87, 97, 118). Poston and colleagues (80) examined the prevalence of overweight and obesity in nearly 700 professional and volunteer firefighters. Body composition was analyzed using foot-to-foot bioelectrical impedance while BMI was calculated using the subjects' height and weight. The average BMI and percent body fat for the professional firefighters was 28.6 $kg \cdot m^{-2}$ and 25.3% respectively while the average BMI and percent body fat for the volunteer firefighters assessed was 29.5 $kg \cdot m^{-2}$ and 26.2%. Overall, 75% of the firefighters examined were considered overweight or obese. According to BMI, the rate of overweight and obesity amongst this sample of firefighters is above that of the national average (72).

The prevalence of overweight and obesity in the firefighting community has continued to increase, placing a real threat to the overall health and level of risk for CVD in this population. Obesity has been related to lower levels of cardiorespiratory fitness among firefighters, a fitness attribute needed to successfully complete many fire ground tasks and operations. Increased levels of obesity have also been associated with decreased vascular health leading to an increase in the risk of a cardiovascular event while on-duty. Firefighters with increased levels of obesity have also displayed altered blood lipid profiles, such as reduced HDL cholesterol, and increased LDL and total cholesterol (21, 23). Greater levels of obesity, especially in the firefighting community may negatively affect other positive CVD risk factors as well as decrease job performance.

Other factors associated with cardiovascular disease risk

In addition to the association of poor physical fitness, sedentary lifestyle, and the prevalence of obesity on CVD risk, additional factors may play a significant role in increasing disease risk. It is well documented that a poor diet high in saturated fatty acids, cholesterol, sugar, and sodium, is strongly associated with altered lipid profiles, obesity, hypertension, and overall increased risk in CVD (94). According to the ACSM (1), positive risk factors for CVD include dyslipidemia, obesity, and hypertension, all of which have been strongly associated with poor dietary habits. A diet high in saturated fatty acids has been significantly related with elevated LDL cholesterol and total cholesterol levels. In addition, if monounsaturated and polyunsaturated fats are substituted for saturated fatty acids a reduction in total cholesterol levels have been reported (94). Furthermore, an increase in dietary cholesterol intake has been associated with increased serum cholesterol levels, leading to an increased risk for CVD according to the ACSM (1, 94). Kris-Etherton et al. (53) suggested decreasing saturated fatty acid and cholesterol intake by replacing those foods with fruits, vegetables, and whole grain food sources as a means to improve lipid profiles. Shrapnel and colleagues (94) also suggest a diet higher in vegetable sources as vegetable intake has been associated with lowering serum cholesterol levels as well as a reduction in blood pressure. Diets with reduced sodium intake have also shown strong relationships with decreased CVD risk as diets higher in sodium have been linked with hypertension.

An additional behavior that has been associated with an increased risk of CVD is sleep. A cross-sectional analysis of over 5000 adult men was performed in order to assess sleep in relation to coronary artery disease. Those who tended to sleep more than 9 hours per night and those sleeping fewer than 6 hours per night had a higher prevalence of myocardial infarction (77). Likewise, Qureshi et al. (81) found an increased risk for disease in those who slept greater than 8 hours per night compared to those sleeping between 6 to 8 hours per night. Wingard and colleagues (115) longitudinally evaluated nearly 5000 adult men and women in regards to sleeping patterns and risk for mortality. These researchers found that mortality rates due to heart disease, cancer, and stroke were lowest for those adults sleeping between 7 hours and 8 hours per night. In comparison, men who slept less than 6 hours or more than 9 hours had a 2 fold increase in death due to CVD related causes compared to men sleeping between 7 and 8 hours per night. The relationship between death rates due to CVD and sleep were similarly reported in the women included in this study as well.

Having shown prevalence of CVD fatalities and elevated incidence of CVD risk among the fire service, in addition to the lack of physical fitness, physical activity, and prevalence of obesity, the irregularity of normal sleeping patterns may be adding to the risk for CVD in this population. As many fire fighters serve 24 hour shift while on-duty, normal sleeping patterns and the ability to sleep for 7 to 8 hours per night may not be attainable. Research has shown an association between altered sleeping patterns with an increased likelihood of death due to CVD related causes when adults either sleep greater than 9 hours per night or less than 6 hours per night (77, 81, 115). The need for objective measures of sleeping patterns among the fire service could give valuable insight for CVD risk stratification in addition to other traditional CVD risk factors.

Section II: Association of Arterial Stiffness with Cardiovascular Disease Risk

Definition and measurement of arterial stiffness

The proximal arteries, such as the aorta, possess different compositional properties than many other arteries located in the human body. For example, the ascending aorta tends to be comprised of higher amounts of elastin, allowing for the absorption of the pulse pressure during systole (37, 54, 56). Arteries found further distally tend to be stiffer with higher amounts of collagen in order to maintain structure and rigidity of the artery (37, 54, 56). Arterial stiffness may be influenced by the nature of the stress and strain of the vascular wall. Factors such as age can show increases in arterial wall thickening which may be representative of atherosclerosis (74). With increased age, fractures and discontinuities of the elastic lamellae of the arterial media occur. This is accompanied by an increase in collagen leading to thickening and a reduced compliance of the artery causing stiffening of the blood vessel (74). Other factors that can alter the health of the vascular system include hypertension (57, 120). Chronically increased systolic blood pressure places a high demand on the elastic properties of the ascending aorta. Similar to increased age, over time chronically high pulse pressure generated inside the central arteries during ventricular contraction causes elastin fiber damage and fracture (57), as well as arterial wall thickening (55). The damage to the elastic properties of the artery lead to a greater production of collagen as the damaged arteries attempt to regain structure and function. Calcification and plaque build-up on the arterial wall, as well as the introduction of advanced glycation end-products (AGE's), may cause arterial wall thickening and stiffening (108). Advanced glycation end-products have been shown to increase arterial stiffness by forming an irreversible link between collagen proteins, which in turn may lead to an increase in pressure and reduced compliance (120). Increased arterial stiffness has also been associated with obesity (90, 93), poor cardiorespiratory fitness (91, 106), and a sedentary lifestyle (91). In more obese populations, arterial stiffness tends to be increased, displaying a positive relationship. In addition, those who lead a more sedentary lifestyle and/or have poor cardiorespiratory fitness show a significant association with increased arterial stiffness.

The gold standard for non-invasively assessing arterial stiffness in humans is accomplished using carotid-femoral pulse wave velocity (cfPWV) (66). Carotid-femoral pulse wave velocity can be calculated by dividing the distance the pulse traveled by the change in time (57), and represents the speed of the pulse along the arterial segment (75). Carotid-femoral pulse wave velocity is representative of the elastic nature of the proximal artery (the arterial segment between the carotid artery and the femoral artery found by palpation). An investigation by Asmar et al. (2) assessed the validity and reproducibility of the cfPWV measurement by comparing the manual measurement to the automatic measurement. The mean difference between the two methods was 0.20 ± 0.45 $m \cdot s^{-1}$ with slightly lower values recorded by the automatic device (manual 11.05 ± 2.58 $m \cdot s^{-1}$ and automatic 10.85 ± 2.44 $m \cdot s^{-1}$, $p < .05$) representing no difference between the two measures. Also, no differences in intra and inter-observer repeatability were seen in cfPWV measurement via automatic device.

As the ventricles contract, a pulse wave is generated and travels distally to the periphery. The pulse generated by ventricular contraction can be measured at the carotid and femoral arteries. The distance between these two cites can be measured above the surface of the body with a fiberglass measuring tape. Before performing a pulse wave velocity measurement, the subject should be at rest for at least 10 minutes and have refrained from eating or drinking beverages containing caffeine for at least 3 hours. The cfPWV measurement is completed with the use of the SphygmoCor device (AtCor Medical, Australia). This device measures the time between the R-wave of the electrocardiogram and the foot of the pressure and distension wave at the site of the measurement (107). By consecutively measuring the two ends of the arterial segment (carotid site and femoral site), the transit time can be calculated and a velocity can be determined. Arterial stiffness and cfPWV are positively related, as the arterial segment loses compliance and becomes stiffer, the pulse wave velocity increases.

Role of arterial stiffness on cardiovascular disease

Vascular health has been shown to be an independent predictor of CVD (6). In terms of risk reduction related to the stiffness of arteries, typically those with more compliant arteries are considered less at risk for CVD compared to those that have more stiff arteries. During systole, the left ventricle contracts and ejects blood into the ascending portion of the aorta and is then distributed among the systemic periphery. Proximal or central arteries possess an elastic attribute that causes the forward traveling pulse wave to be deflected at many bifurcation sites and discontinuities of the arterial tree. From these bifurcations, the forward traveling wave is reflected back to the aorta causing an interaction of the two waves. The speed at which the two waves travel depends on the stiffness or compliance of the arteries measured via cfPWV. As cfPWV increases due to an increase in arterial stiffening, the reflected wave returns much quicker, causing a disturbance of pressure seen in the aorta. If the reflected wave returns during systole, an augmentation of the aorta occurs causing an increase in aortic pressure that the left ventricle must overcome in order to eject blood into the periphery (increased left ventricular afterload). Consequently, due to the early wave reflection, systolic blood pressure tends to increase. The early wave reflection that is present when arteries are less compliant also causes a decrease in central diastolic pressure resulting in a reduction of coronary artery perfusion pressure (46, 57). In contrast, cfPWV in healthier compliant central arteries tends to be slower allowing reflected waves to return to the central aorta during diastole. The return of the ascending wave during diastole augments diastolic pressure and therefore increases coronary perfusion (73, 75).

A strong positive association between age and cfPWV has been seen in many investigations (55, 57, 73). Lakatta and colleagues (55) reported that age associated increases in arterial stiffness may be due to arterial wall thickening, luminal dilation, and a reduction in compliance. The investigators suggest that the increase in cfPWV, indicative of stiffened arteries, is linked to structural alterations of the arteries, such as increased collagen, reduced elastin, elastin fractures, and increased calcification. Furthermore, the area where the damage has occurred is an important factor due to the difference in pressures seen along the arterial tree. For example, when no damage is present at the ascending aorta, the artery is more elastic in nature and can withstand the increased pressure during systole. In comparison, a stiffer artery at the same location where increased collagen may be present due to age or disease, a decrease in compliance is observed. The decrease in arterial compliance produces an increase in pressure seen at the aorta that can lead to an increased left ventricular workload (73). This was seen in an investigation performed by Lehmann et al. (58) as healthy controls had superior aortic compliance measures compared to patients with CVD or two or more CVD risk factors such as hypertension, diabetes, current smokers, and those experience angina. A significant inverse relationship was seen between aortic compliance and PWV in this investigation, suggesting that an increase in PWV may in part be due to a decrease in aortic compliance (58).

In terms of increased risk of CVD, an increase in cfPWV has been shown to be an independent predictor of CVD (64). In a longitudinal investigation performed by Sutton-Tyrell et al. (101) cfPWV was measured in a large sample of nearly 2,500 adults. Of the deaths that occurred during the investigation, nearly half resulted from cardiovascular causes. From these fatalities, previously measured cfPWV revealed that a higher cfPWV measure was associated with cardiovascular mortality due to other causes such as stroke. Also, those who recorded cfPWV measures of greater than 6.5 $m \cdot s^{-1}$were seen to be at a higher risk for CVD than those below this value. Mitchell et al. (66) found that a higher cfPWV was associated with a near 50% increase in risk of CVD, and that arterial stiffness measured via cfPWV was strongly associated with an increased risk for experiencing a first cardiovascular event. Contrary to the findings reported by Sutton-Tyrell et al. (101), subjects from the investigation done by Mitchell et al. (66) with cfPWV measurements of greater than 11 $m \cdot s^{-1}$ were seen to be at the highest risk for CVD compared to those with cfPWV values below 7.7 $m \cdot s^{-1}$. Furthermore, a longitudinal study performed by Hansen et al. (43) found that in middle-aged and older adults (ages 40-70 years) an increased cfPWV measure was able to predict cardiovascular events above and beyond that of traditional CVD risk factors. This investigation suggested that for each one standard deviation increase in cfPWV (3.4 $m \cdot s^{-1}$) the risk of a cardiovascular event increased by as much as 20%. An investigation by Vlachopoulos et al. (109)

corroborate with Hansen et al. (43) findings of the association between increased cfPVW and increased cardiovascular events. This investigation evaluated 17 longitudinal studies of nearly 16,000 adult subjects finding that an increase in cfPWV by 1.0 $m \cdot s^{-1}$ corresponded to an age, sex, and risk factor adjusted risk of 14%, 15% and 15% in total cardiovascular events, cardiovascular mortality, and all-cause mortality, respectively.

Association of Obesity with arterial stiffness

Although much of the literature has reported an increase in arterial stiffness due to age, Scuteri and coworkers (90) found an increase in cfPWV when levels of overweight and obesity increased, independent of age. The investigators assessed over 6,000 subjects and found that among all age groups, even in those less than 35 years of age, increases in BMI were associated with higher levels of cfPWV. Furthermore, when visceral adiposity was estimated via waist circumference, the positive correlation between the estimate of the high risk fat depot and cfPWV was stronger than that of BMI and cfPWV. The information gained from this study is of great use to the practitioner assessing CVD risk as both waist circumference and cfPWV are non-invasive measures that can be performed in a laboratory or field based setting.

An investigation performed by Shim and colleagues (93) assessed arterial stiffness among groups of lean and overweight/obese women (63 ± 7 years of age). Obesity was assessed via body mass index and was shown to be an independent determinant of arterial stiffness among the overweight/obese group. The noted increase in arterial stiffness measured via cfPWV seen in the overweight/obese group was associated with reduced arterial distensibility and a decrease in the elastic characteristics of the aorta.

Over the last decade among the firefighting community, a trend for increased obesity has been present. Measures of overweight and obesity among firefighters have been reported as high as 75% (80, 87, 97, 116, 118), exceeding the national average of the United States (72). In relation to the results presented by Scuteri et al (90) and Shim et al. (93), the heightened levels of obesity among firefighters may introduce an elevated risk of CVD in relation to increases in cfPWV.

An investigation by Fahs et al. (31) measured the acute effects of firefighting tasks on arterial stiffness. Subjects included 69 male firefighters with a mean age and body mass index of 28 ± 1 year and 26.9 ± 0.5 kg·m^{-2} (range 20.3–37.7 kg·m^{-2}), respectively. All subjects completed a three hour bout of firefighting tasks with tasks lasting 15 – 25 minutes separated by 10 – 15 minutes of rest. Examples of the firefighter operations included charged hose advancement, forcible entry, search and rescue, and ventilation tasks all while wearing full firefighting gear including self-contained breathing apparatus'. Carotid-femoral PWV measurements were taken before and after the three hour bout of firefighting maneuvers. The main finding from this investigation was that following the 3 hour bout of simulated tasks, cfPWV was significantly acutely increased. Overall, average pre and post cfPWV measurements were 6.3 ± 0.1 m/s and 6.5 ± 0.1 m/s respectively. Although these measures of cfPWV are considered within the normal range (55, 66), the limitation to this investigation was that all firefighters included were considered low risk for CVD and sudden cardiac events. When assessing CVD risk among the firefighting community as a whole, many firefighters are considered moderate to high risk with the leading cause of death for the past decade being sudden cardiac death and factors related to CVD. If a significant increase in arterial stiffness was associated with a simulated bout of firefighting operations in healthy young firefighters, the risk for cardiac events may be much higher for older and obese firefighters completing similar tasks.

Association of Physical Activity with arterial stiffness

An investigation performed by Seals and colleagues (91) postulated a possible mechanism for the effect physical activity has on arterial stiffening. This study suggests that regular aerobic exercise may minimize or even reverse age-related structural changes that typically occur in the arterial walls of aging sedentary adults. The authors imply that a reduced oxidative stress from incorporating aerobic exercise may be a possible contributing mechanism. Furthermore when comparing adults who regularly perform aerobic exercise to those who lead a sedentary lifestyle, those leading more active lifestyles demonstrated smaller or no age related increases in proximal arterial stiffness. In fact, implementing a 12 week moderate intensity exercise intervention, such as brisk walking, has shown marked improvements in carotid artery compliance. This improvement was even seen in middle-age and older adults who previously lived a more sedentary lifestyle.

Folsom et al. (39) examined the carotid artery wall thickness in 800 subjects ranging in age from 45 years to 64 years of age. The carotid artery wall thickness measure utilized in this investigation was a means to account for CVD risk due to the amount of atherogenesis that had occurred in the study population. An interesting finding was that physical inactivity, estimated via Baecke physical activity questionnaire, was strongly associated with increased carotid artery wall thickness. The thickness measure was likely due to the atherosclerotic processes such as vascular changes in elastic and collagen as well as increased calcification. These measures would likely decrease the distensibility and compliance of the artery leading to an increase in arterial stiffness. These factors may ultimately lead to an increase in CVD risk that may be associated with a lack of physical activity. To corroborate with this finding, Moreau and colleagues (68) found that carotid artery compliance was greater in women who performed regular aerobic exercise compared to their sedentary peers. Furthermore, previously sedentary women completed a 12 week exercise intervention involving a walking program done a moderate intensity (65%-85% max heart rate) for 40-45 minutes per day on 4-5 days per week. Following the aerobic exercise intervention, the previously sedentary group showed signs of improved compliance of the proximal aorta. These results suggest that adhering to a regular moderate intensity aerobic exercise regimen may benefit and improve vascular compliance, a measure associated with arterial stiffness and risk for CVD.

Physical activity among firefighters has been previously investigated (23). Nearly half of the firefighters assessed in this investigation exercised three or fewer times per week and/or did not accumulate the minimum requirement of 150 total minutes per week of moderate intensity aerobic exercise (1). In terms of CVD risk present in the firefighting population, increasing physical activity frequency and duration showed favorable effects on decreasing CVD risk. In relation to an increase in arterial compliance (decreased arterial stiffness) from the aforementioned investigations, firefighters may show signs of improved vascular functioning and decreased CVD risk when adhering to an exercise program.

Association of Cardiorespiratory Fitness with arterial stiffness

An increase in cardiorespiratory fitness (CRF) has been associated with more compliant arteries in adults (106). Vaitkevicius et al. (106) compared a healthy, sedentary group of 146 adults ranging in age from 21 to 96 years of age (men: 55 ± 17 years of age; women: 53 ± 18 years of age) to a group of 14 endurance trained men ranging in age from 54 to75 years of age. Adults were excluded from the sedentary group if: blood pressure was greater than 160/95 mmHg, had the presence of CVD, were current smokers, were currently taking cardiovascular medication, and were participating in aerobic exercise for at least 20 minutes at least three times per week. The subjects in the endurance trained group were included if they were regularly competing in local distance running events and had a VO$_2$ max at least one standard deviation above the mean for their age matched non-trained counterparts (average VO$_2$ max among the endurance trained group was 44 ± 3 ml·kg^{-1}·min^{-1}). All cardiorespiratory values were collected via a modified Balke treadmill exercise test. Arterial stiffness was found to have an inverse relationship with cardiorespiratory fitness. Older adults that were endurance trained had lower cfPWV measures compared to the sedentary controls. Furthermore, among the sedentary group, members above the age of 70 years exhibited a strong inverse association between cfPWV and CRF level, regardless of how fitness was attained (i.e. training or genetic factors). Similarly, Boreham and colleagues (9) measured arterial stiffness in relation to CRF among 405 young normal weight adults. CRF was estimated using a submaximal cycle protocol where workload was increased every 3 minutes until a heart rate of approximately 170 beats per minute was attained. The main finding from this study was that a significant inverse relationship between CRF and arterial stiffness was found. A possible mechanism for this relationship may be explained by an investigation performed by Matsuda et al. (63) involving an animal model. During this study, young male rats underwent 16 weeks of varying aerobic exercise programs such as running and swimming. When comparing the exercised rats to sedentary controls, the exercise group had significantly increased elastin content of the aorta with no increase in collagen content. Furthermore, the treatment group showed signs of lower elastin calcium content, as calcium deposits in elastin are correlated with aortic distensibility (the distensibility of the aorta increases as elastin calcium content decreases). Also, due to the chronic training program, the increased pressure seen in the aorta during exercise may have stimulated the synthesis of elastin in the proximal arteries. The limitation to this investigation is that the relationship between arterial stiffness with cardiorespiratory fitness was seen in a non-human model. However, the mechanisms at play may give some insight to the human model in relation to decreased arterial stiffness and increased CRF (9, 106).

The National Fire Protection Association (70) recommends a minimum cardiorespiratory fitness of 42.0 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in order to successfully complete fire ground tasks. An investigation by Baur and coworkers (4) assessed CRF among a cohort of over 900 firefighters and found only 44% exceeded the minimum guideline. Furthermore, CRF was assessed in an additional group of 214 male firefighters and found that over one-fourth failed to achieve the minimum requirement (21). As the risk for CVD continues to increase among firefighters, the relationship between decreased levels of CRF and increased levels of arterial stiffness may be evident. As stated previously, increased levels of arterial stiffness was an independent predictor of sudden cardiac death and death due to CVD, which is the leading cause of death among the fire service. Future interventions may consider exercise programs that enhance levels of CRF in an attempt to reduce arterial stiffness and CVD risk.

Section III: Conclusion

The firefighting profession is a physically demanding and hazardous occupation. The need for physical fitness and overall health is a premium for successful completion of fire ground duties. Over the past decade, the prevalence of fatalities due to cardiovascular disease has contributed to the largest cause of death among the fire service compared to any other cause. Many firefighters possess several CVD risk factors including obesity, hypertension, dyslipidemia, diabetes and pre-diabetes, sedentary lifestyle, as well as increased age and a family history of CVD. In addition, behaviors associated with increased CVD risk such as poor CRF, diet, and altered sleep patterns are commonplace in the fire service.

The need for objective measures of CVD risk, such as arterial stiffness, physical activity levels, CRF levels, and obesity is apparent. The use of cfPWV to assess arterial stiffness will give valuable information in evaluating the CVD risk of firefighters. The literature presents many findings that have shown effective ways to attenuate or decrease the risk of CVD in terms of improving arterial stiffness. Increasing physical activity and physical fitness, and decreasing the prevalence of obesity have exhibited profound effects on CVD risk reduction in both the general adult and firefighting populations, respectively.

CHAPTER III

ASSESSMENT OF CARDIOVASCULAR DISEASE RISK FACTORS IN VOLUNTEER AND PROFESSIONAL FIREFIGHTERS

INTRODUCTION

Recent evidence suggests that death rates of on-duty firefighters are overwhelmingly due to non-fire related causes (33, 35, 84). Nearly 100 firefighter fatalities occur annually in the United States, of which, nearly 45% are due to cardiovascular disease (CVD) (33). In 2006, 52% of firefighter fatalities occurred in volunteer firefighters (32). In addition, 50% of those deaths were due to CVD, whereas 39% of the deaths occurring in professional firefighters were due to CVD (32). In 2010, overall death rates due to CVD increased to 49%, with 61% of these deaths occurring in volunteer firefighters (35). More recently in 2013, 29 firefighter fatalities were due to sudden cardiac death/myocardial infarction, accounting for the largest number of firefighter fatalities that year (34). Analyzing specific cases in which all firefighter deaths occurred, the largest proportion was due to myocardial infarctions where previous medical records revealed that many had been diagnosed with CVD risk factors such as hypertension, diabetes, and previously reported heart problems such as prior myocardial infarctions, cardiac bypass, or angioplasty (33, 35, 84). Autopsies and post mortem medical records reported additional cases with arteriosclerotic heart disease that was previously unreported/undetected**.**

The firefighter fatality data from 2010 to present demonstrated that more deaths have occurred in volunteer firefighters compared to professional firefighters, with a vast majority due to CVD (32, 33, 34, 35, 48, 84). Volunteer firefighters tend to remain occupationally active in the fire service well beyond the employed ages of professional firefighters. Most firefighters who experience sudden cardiac death over the age of 60 years are volunteers (33). As outlined by the American College of Sports Medicine (ACSM) (1), males over the age of 45 years and females over the age of 55 years accrue an additional positive risk factor for CVD due to age alone. Additionally, many volunteer firefighters tend to serve small rural communities, where most have not received either proper health screenings or are required to pass minimal or no physical ability requirements for firefighting operations (33, 48). Pearson et al. (78) reported that the prevalence of cardiovascular disease mortality in the general population of the Unites States was greater in rural versus urban communities. Thus, the lack of sufficient screening and other environmental factors could be linked to higher CVD fatality rates in volunteer firefighters serving rural communities compared to professional firefighters serving urban municipalities (35, 41).

Most of the research involving firefighter health has been limited to professional firefighters, whereas 70% of the 1.1 million firefighters in the United States are volunteers (84). Although data pertaining to blood lipid profiles (98), obesity (98), smoking (41), and hypertension (41, 49, 98) have been studied in professional firefighters, a lack of information regarding these CVD risk factors exists among the volunteer population and has yet to be extensively investigated. Information regarding cardiovascular disease risk in volunteer firefighters may guide behavioral interventions and policy development to decrease the risk of sudden cardiac death among volunteer firefighters. Therefore the purpose of this investigation was to describe and compare the prevalence of CVD risk factors and associated health behaviors between professional and volunteer firefighters. We hypothesized that the prevalence of CVD risk factors among volunteer firefighters would be greater than professional firefighters. A secondary purpose was to quantify the level of CVD risk among firefighters in the state of Kentucky, and to compare the prevalence of obesity of Kentucky firefighters to the state and national population. We hypothesized that the majority of firefighters would be classified as moderate-to-high CVD risk and have a greater prevalence of obesity compared to state and national populations.

SPECIFIC AIMS

The overall goal of this investigation was to determine the prevalence of CVD risk between professional and volunteer firefighters in the state of Kentucky. To achieve this goal, the following aims were proposed:

1. Compare the prevalence of CVD risk factors and associated health behaviors between professional and volunteer firefighters.
2. Quantify the level of CVD risk among firefighters in the state of Kentucky, and to compare the prevalence of obesity of Kentucky firefighters to the state and national population.

Delimitations

1) Volunteer and professional firefighters from the state of Kentucky.

Assumptions

1) Survey responses were accurate.

METHODS

Experimental Design and Subjects

An abbreviated version of the Behavioral Risk Factor Surveillance System (BRFSS) survey was sent via email to approximately 4,000 Kentucky volunteer and professional firefighters. The BRFSS survey was developed by the Centers for Disease Control and Prevention (11) and is currently administered annually to the general population in the United States. The BRFSS is a validated instrument (99, 119) that is used to obtain information pertaining to cardiovascular disease risk factors such as: age, height and weight (used to calculate BMI: body mass index), physical activity levels, family history of cardiovascular disease, cigarette smoking, resting blood pressure, blood lipid profiles, pre-diabetes, and diabetes.

The abbreviated BRFSS survey was implemented using Qualtrics software (Qualtrics, LLC, USA) and was available online during a two week period. In order to gain access to the firefighters and attempt to improve the survey response rate, a state Fire Agency distributed the link via email to all available volunteer and professional firefighters with an email address. Each survey consisted of a cover letter explaining that participation was voluntary and would not have consequences regarding occupational status. The cover letter stated that the information obtained from the survey would be used solely for research purposes and that the project had no affiliation with associated firefighter unions. No identifiable information (e.g., name, identification number, personal address, etc.) was collected. The study's procedures were approved by the University's Institutional Review Board.

Since firefighting is a physical demanding profession, Smith et al. (97) suggested using the ACSM (1) guidelines to stratify cardiovascular disease risk, due to the addition of physical activity (sedentary lifestyle) as a possible risk factor CVD. According to ACSM (1), positive risk factors for cardiovascular disease include: age (men ≥ 45 yr; women ≥ 55 yr), family history (myocardial infarction or sudden death before 55 yr of age in father or other male first-degree relative, or before 65 yr of age in mother or other female first-degree relative), cigarette smoking (current smoker or those who have quit in the past six months), obesity (BMI ≥ 30 $kg \cdot m^{-2}$), hypertension (systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥ 90 mmHg, or taking antihypertensive medications), dyslipidemia (total cholesterol ≥ 200 $mg \cdot dL^{-1}$, or taking cholesterol lowering medications), pre-diabetes (fasting glucose ≥ 100 $mg \cdot dL^{-1}$ and < 126 $mg \cdot dL^{-1}$), and sedentary lifestyle (< 30 minutes of moderate intensity physical activity on at least 3 $d \cdot wk^{-1}$ for at least three months). All positive risk factors for each subject were summed in order to classify CVD risk as low, moderate, or high according to ACSM standards. Cardiovascular disease risk stratification was identified as follows: Low risk: asymptomatic with ≤1 cardiovascular disease risk factor; Moderate risk: asymptomatic with ≥2 cardiovascular risk factors; High risk: known cardiovascular, metabolic or pulmonary disease or with ≥1 signs or symptoms of cardiovascular, metabolic or pulmonary disease (i.e. pain, discomfort in the chest or other areas that may result from ischemia, shortness of breath at rest or with mild exertion, dizziness or syncope, orthopnea or paroxysmal nocturnal dyspnea, ankle edema, palpitations or tachycardia, intermittent claudication, known heart murmur, unusual fatigue or shortness of breath with usual activities).

Statistical Analysis

Descriptive characteristics of all CVD risk factors were assessed and presented as means and standard deviations for continuous variables or as a percentage for dichotomous responses (e.g., Current smoker: % responding positively). Independent samples *t*-tests were used to compare CVD risk factors and related health behaviors between professional and volunteer firefighters. Chi-square tests for independence were conducted when comparing dichotomous CVD risk factor outcomes. Firefighters were also stratified into BMI tertiles to compare CVD risk factors according to levels of obesity using analysis of variance tests per continuous outcome and chi square tests of independence per dichotomous outcome. In addition, national and state obesity data recorded from the BRFSS were compared to the respondents by calculating difference scores (difference/mean) between survey respondents and archived BRFSS data. All analyses were performed using IBM SPSS (version 22, New York, United States) statistical software. Two-tailed probability values of < 0.05 were considered statistically significant.

RESULTS

A total of 205 surveys (5.125% response rate) were returned to the principal investigator. Of these surveys, 175 were fully completed and used for data analysis. Table 3-1 presents the demographic data of all survey responders. The majority of respondents were classified as firefighters (34.9%), whereas drivers/engineers (6.3%) represented the smallest cohort. The age groups 30 – 39 and 40 – 49 years of age had the greatest representation among all personnel, whereas the age group of 22 – 29 years of age had the smallest representation. Inconsistent with the United States' population (72, 12), more survey respondents were classified as obese (46.3%) than overweight (40.6%), and only 13.1% of respondents were considered healthy weight according to BMI. Also, most of the respondents were reported from all geographical regions of Kentucky except the southern-most counties, where only 1.1% of the total respondents were residents serving that area. However, the southern area contained the fewest counties in terms of geographical distribution.

Table 3-1. Characteristics of questionnaire responders (N = 175).

Characteristic	Professional (n = 140) n (%)	Volunteer (n = 35) n (%)
Firefighter Type		
Firefighter	55 (39)	6 (17)
Captain	22 (16)	5 (14)
Lieutenant	18 (13)	1 (3)
Battalion Chief	16 (11)	1 (3)
Deputy/Assistant Chief	16 (11)	8 (23)
Driver/Engineer	6 (4)	5 (14)
District Chief	5 (4)	9 (26)
Missing Data	2 (1)	0 (0)
Sex		
Men	136 (97)	35 (100)
Women	4 (3)	0 (0)
Age		
22-29	11 (8)	3 (9)
30-39	48 (34)	3 (9)
40-49	53 (38)	9 (26)
50-59	24 (17)	9 (26)
≥60	4 (3)	11 (31)
BMI Category		
Underweight	0(0)	0 (0)
Healthy Weight	19 (14)	4 (12)
Overweight	60 (43)	11 (31)
Obese I	34 (24)	11 (31)
Obese II	13 (9)	7 (20)
Morbidly Obese	14 (10)	2 (6)
Demographics		
Northern KY	0 (0)	28 (80)
Southern KY	0 (0)	2 (6)
Eastern KY	31 (22)	5 (14)
Western KY	48 (34)	0 (0)
Central KY	61 (44)	0 (0)

BMI: Body mass index; KY: Kentucky.

A descriptive comparison of CVD risk factors between volunteer and professional firefighters is shown in Table 3-2. Volunteer firefighters were significantly older and more likely to be classified as current smokers than professional firefighters. Volunteer firefighters may have been more likely to be hypertensive but considered not statistically different. There were no differences in BMI, exercise behaviors, family history, and prevalence of dyslipidemia and diabetic status.

Table 3-2. Comparison of self-reported cardiovascular disease risk factors between 175 professional and volunteer firefighters (Mean ± SD).

Risk Factor	Professional (n = 140)	Volunteer (n = 35)	p	χ^2
Age (yr)	41.7 ± 9.2	50.8 ± 12.9*	<0.001	
Body Mass Index ($kg \cdot m^{-2}$)	30.6 ± 6.1	31.7 ± 6.1	0.351	
Sedentary Lifestyle				
Aerobic Exercise ($d \cdot wk^{-1}$)	2.7 ± 1.8	2.0 ± 2.1	0.071	
Aerobic Exercise ($min \cdot session^{-1}$)	42.7 ± 36.0	30.7 ± 38.6	0.084	
Family History (n, %)	28 (20)	8 (20)		0.708
Cigarette Smoking (n, %)	8 (6)	6 (17)		0.026†
Hypertension (n, %)	21 (15)	10 (29)		0.060
Dyslipidemia (n, %)	57 (41)	16 (46)		0.592
Pre-diabetes (n, %)	14 (16)	5 (23)		0.466
Diabetes (n, (%)	8 (6)	4 (11)		0.232

*$p < 0.05$, Represents comparison between Professional and Volunteer firefighters.

†$\chi^2 < 0.05$, Represents the comparison of the proportion of Professional versus Volunteer firefighters that are classified positively versus not classified positively with each health outcome.

Table 3-3 displays the comparison of the prevalence of each CVD risk classification between professional versus volunteer firefighters. A smaller proportion of volunteer firefighters were classified as low risk for CVD and a greater proportion were classified as moderate risk for CVD compared to professional firefighters. Statistically, there was no difference between the two groups for those classified as high CVD risk.

Table 3-3. Comparison of the prevalence of professional versus volunteer firefighters classified in various cardiovascular disease (CVD) risk classifications.

	Professional (n = 140)	Volunteer (n = 35)
Low Risk for CVD, (%, n)	42 (59)	9 (3) †
Moderate Risk for CVD, (%, n)	44 (61)	71 (25) †
High Risk for CVD, (%, n)	14 (20)	20 (7)

†$\chi^2 < 0.05$, represents the comparison of the proportion of professional versus volunteer firefighters in each risk classification.

When analyzing firefighters by BMI classification, the majority of subjects were classified as either overweight or obese (Table 3-4). The mean BMI among all firefighters in the sample was 30.8 ± 6.1 kg·m^{-2}. The obese group had significantly greater BMI and body mass than overweight and normal weight groups. Furthermore, the overweight group had significantly greater BMI and body mass compared to the normal weight group. The proportion of obese firefighters diagnosed with pre-diabetes and diabetes was greater compared to the normal weight and overweight groups, respectively. Regarding non-BMI modifiable CVD risk factors there were no significant differences between the proportion of firefighters in any BMI classification for hypertension, dyslipidemia, smoking status, and living a sedentary lifestyle.

Table 3-4. Comparison of self-reported anthropometrics and cardiovascular disease risk factors among all firefighters stratified by body mass index classification (N = 175).

	Normal weight (n = 23)	Overweight (n = 71)	Obese (n = 81)
	BMI < 25.0 kg·m^{-2}	BMI 25.0 – 29.9 kg·m^{-2}	BMI ≥ 30.0 kg·m^{-2}
Age (yr)	41.6 ± 11.0	41.7 ± 10.3	45.6 ± 10.5
Height (cm)	181.1 ± 7.2	179.8 ± 6.9	181.2 ± 7.4
Weight (kg)	77.8 ± 7.6	88.2 ± 7.2*	117.9 ± 17.1*†
Body mass index (kg·m^{-2})	23.7 ± 1.0	27.3 ± 1.4*	36.0 ± 5.2*†
Sedentary Lifestyle			
Aerobic Exercise (d·wk^{-1})	3.3 ± 2.1	2.6 ± 1.8	2.3 ± 1.9
Aerobic Exercise (min·session^{-1})	47.6 ± 28.4	43.0 ± 40.2	35.9 ± 35.5
Family History (n, %)	6 (26)	11 (15)	19 (24)
Cigarette Smoking (n, %)	2 (9)	3 (4)	9 (11)
Hypertension (n, %)	2 (9)	10 (14)	19 (24)
Dyslipidemia (n, %)	7 (30)	27 (38)	39 (48)
Pre-diabetes (n, %)	0 (0)	5 (7)	14 (17)*
Diabetes (n, %)	1 (4)	2 (3)	9 (11)*†

Unless otherwise noted, data are presented as mean ± SD.

*Different from the normal BMI group ($p < 0.05$).

†Different from the overweight group ($p < 0.05$).

A comparison of self-reported health behaviors associated with CVD risk are displayed in Table 3-5. Volunteer firefighters reported consuming fewer servings of fruits per day compared to professional firefighters. There were no differences between professional and volunteer firefighters for sleep duration, alcohol consumption, vegetable intake, soda intake, fast food intake, stress, and depression.

Table 3-5. Self-reported behaviors associated with cardiovascular disease risk between 175 professional and volunteer firefighters.

Factor	Professional (n = 140)	Volunteer (n = 35)	*p*	χ^2
Sleep duration ($hr \cdot d^{-1}$)	6.4 ± 1.1	6.7 ± 1.2	0.325	
Tobacco users (n, %)	21 (15)	7 (20)		0.173
Alcohol consumption				
Drink ($d \cdot wk^{-1}$)	1.2 ± 1.3	0.7 ± 1.4	0.408	
Drink per sitting	2.1 ± 2.2	1.6 ± 2.5	0.542	
Dietary intake				
Fruit ($serving \cdot day^{-1}$)	1.1 ± 1.1	0.8 ± 0.7	0.027*	
Vegetable ($serving \cdot day^{-1}$)	0.9 ± 0.9	0.5 ± 0.6	0.052	
Soda intake ($serving \cdot day^{-1}$)	0.6 ± 1.1	0.8 ± 1.3	0.426	
Fast food intake per week	3.0 ± 2.5	3.1 ± 2.3	0.641	
Stress ($day \cdot month^{-1}$)	3.6 ± 5.4	2.3 ± 4.9	0.233	
Depression ($d \cdot month^{-1}$)	2.4 ± 4.2	1.4 ± 2.7	0.075	

Unless otherwise noted, data are presented as mean ± SD.

*Represents comparison between Professional and Volunteer firefighters ($p < 0.05$).

Table 3-6 represents the prevalence of obesity data recorded from the BRFSS according to the United States population, the Kentucky state population, and firefighters from the current investigation. On average, the prevalence of obesity among Kentucky citizens was greater than the U.S. population. The prevalence of overweight and obesity among professional firefighters was greater than state and national averages. The prevalence of obesity among volunteer firefighters was 57%, nearly twice as high as the prevalence obese citizens in the state of Kentucky.

Table 3-6. Prevalence of obesity among Kentucky Firefighters (N = 175), Kentucky citizens (N=10,570), and National BRFSS respondents, 2012 (N = 442,230).

	Normal (%)	Overweight (%)	Obese (%)	Rel. Diff. Overweight from KY population (%)	Rel. Diff. Obese from from KY population (%)
United States	34	36	28	0.0	-10.2
Kentucky	31	36	31	----	----
Professional FF	14	43	44	17.7	34.7
Volunteer FF	11	31	57	-14.9	59.1
Kentucky FF	13	40	46	10.5	39.0

Rel. Diff.: Relative Difference.

DISCUSSION

The purpose of this investigation was to quantify and compare CVD risk factors and related health behaviors between professional and volunteer firefighters. Volunteer firefighters may be at a greater risk for CVD than professional firefighters. When classifying CVD risk according to ACSM (1) guidelines, 91.4% of volunteer firefighters were considered at moderate-to-high risk compared to 57.9% of professional firefighters. This was due, in large part, to the older age and smoking status of volunteer firefighters and greater proportion of volunteer firefighters in the obese BMI classification (33). The difference in age in the current investigation was consistent with previous reports on volunteer firefighters (33, 50). In addition, there were non-significant trends ($p = 0.06$) suggesting that volunteer firefighters were more likely to be hypertensive than professional firefighters. Similarly, Geibe et al. (41) found that previously diagnosed CVD (or those classified as high risk according to ACSM guidelines), current cigarette smoking, and hypertension were strong predictors of fatality among firefighters who experienced CVD events while on-duty. In the present study, these predictors were more prevalent among volunteer firefighters. Given the high prevalence of volunteer firefighters classified as having moderate or high CVD risk, it is recommended that a physician's clearance is obtained prior to starting an exercise program (1). This may be a concerning issue as insufficient disease screening is already an emerging issue among volunteer firefighters (48).

To derive health benefits from physical activity and exercise, it is recommended that individuals perform at least 150 $\text{min}\cdot\text{wk}^{-1}$, or perform greater than 30 minutes of moderate intensity physical activity on 5 or more $\text{d}\cdot\text{wk}^{-1}$, or perform 20 minutes of vigorous intensity aerobic activity 3 or more d·wk^{-1} (1, 13). Using the average frequency and duration per session values reported in the present study, volunteer firefighters accumulated 62 min·wk^{-1} and professional firefighters accumulated 115 min·wk^{-1} of moderate intensity physical activity. From these data, it is apparent that neither type of firefighter is meeting the recommended physical activity guidelines. Similarly, a previous investigation demonstrated that many firefighters do not meet physical activity recommendations (23).

The majority of firefighters were classified as overweight or obese (86.9%) with an average body mass index of 30.8 kg·m^{-2}. An alarming finding was the prevalence of obese firefighters, as a larger percentage of firefighters were considered obese (46.3%) than overweight (40.6%; Table 3-6). Soteriades et al. (98) reported similar findings as 40% of 332 professional firefighters were classified as obese. Yoo and colleagues (118) assessed BMI in volunteer firefighters and found 35% to be overweight and 41% obese. The present study found 31% of the volunteer firefighters classified as overweight and 57% as obese. These data demonstrate a dissimilar trend with the U.S. population, where nearly 33% of adults were considered obese according to BMI (11, 72). Furthermore, the general population of Kentucky had a greater percentage of obese citizens compared to the U.S. population (Table 3-6). However, when comparing both professional and volunteer firefighters to the state population, both types of firefighters have a greater prevalence of obesity compared to the state population. This illustrates an independent effect of the fire service on obesity levels compared to the state and national norms. Possible explanations for this finding could be that professional firefighters work 24 hour shifts as a cohesive group where healthy and/or non-healthy behaviors may be similar between co-workers. Volunteer firefighters have primary careers in addition to firefighting, leading to limited time for exercise and healthy meal options. Also, volunteer firefighters tend to serve rural communities (33, 48) where residents of these areas have been shown to be less likely to meet physical activity recommendations (76). Both explanations may give some insight as to the elevated BMI and CVD risk among the firefighting community as obesity is strongly associated with hyperlipidemia, hypertension, and pre-diabetes/diabetes (21, 23, 27).

In terms of behaviors associated with CVD risk such as diet, volunteer firefighters consumed fewer servings of fruit compared to professional firefighters. There was also a non-significant ($p = 0.052$) trend for volunteer firefighters to consume fewer servings of vegetables compared to professionals. The difference in dietary behaviors between the two groups could have an impact on the elevated CVD risk among volunteers and may be explained by the communities in which they serve. Professional firefighters tend to serve urban communities whereas volunteer firefighters tend to serve rural communities. Rural compared to urban communities have been shown to have less accessibility (45, 96) to marketplaces where fresh produce is readily available. Hosler et al. (45) explained that rural communities had the lowest density by population of total food stores which may explain why the volunteer firefighters tended to consume fewer fruit servings compared to professional firefighters.

Several strengths of the study should be noted. The BRFSS is a validated instrument (99, 119) that allowed for descriptive comparisons in obesity between Kentucky firefighters and state and national samples. A prior investigation performed by Scanlon et al. (87) assessed volunteer firefighters via a non-validated survey in an attempt to identify cardiac risk. A second study conducted by Yoo and colleagues (118) assessed the prevalence of CVD risk among volunteer firefighters using the BRFSS but did not classify CVD risk according to ACSM (1) standards, compare their findings to a sample of career firefighters' in the same geographic region, or compare the prevalence of firefighter obesity to state and national normative data. The use of ACSM (1) standards for CVD risk stratification may be a superior classification tool and was used in this investigation as suggested by Smith et al. (97) due to the physical demands of the firefighting profession.

This study also differs from the aforementioned investigations due to the additional assessment of behaviors associated with CVD risk. Since volunteer firefighters were more likely to be considered moderate and high risk compared to professional firefighters, self-reported lifestyles and behaviors were analyzed. Volunteer firefighters showed a significant difference in dietary fruit intake but no differences were noted in sleep duration, depression or stress compared to professional firefighters. Due to the nature of shift work for professional firefighters or maintaining a career in addition to volunteer firefighting, adequate sleep may not be attainable across the firefighting profession. A correlation has been demonstrated between altered sleeping patterns and an increased likelihood of death due to CVD related causes when adults either sleep greater than 9 hours per night or less than 6 hours per night (77, 81). Additionally, Wingard et al. (115) found that mortality rates due to heart disease, cancer, and stroke were lowest for those adults sleeping between 7 hours and 8 hours per night. On average, both professional and volunteer firefighters in this investigation self-reported less than 7 hours of sleep per night which may demonstrate an increased CVD risk beyond ACSM (1) risk stratification criteria.

This study has several limitations. First, all data were self-reported via the BRFSS where risk factors such as hypertension, dyslipidemia, and pre-diabetes were answered dichotomously as “yes” or “no” based on their last meeting with a physician, so exact values were not given. Additionally, an equal representation of professional and volunteer firefighters was not present, likely due to limited internet access to those serving rural communities dominated by volunteer firefighters. However, the trends that emerged from this investigation regarding enhanced CVD risk among volunteer firefighters were congruent with previous research (32, 35). Furthermore, the differences in many modifiable CVD risk factors between volunteer and professional firefighters were considered not significant. A larger sample of volunteer firefighters may have provided the statistical power necessary to identify true differences in these behaviors between groups. Also, because the present study was limited to nearly all male subjects, the results are not generalizable to female firefighters.

Several practical conclusions can be made from the results of this investigation. The importance for disease screening and prevention is becoming more critical as the prevalence of moderate to high CVD risk among professional and volunteer firefighters may be greater than previously reported (72, 98, 118). However, before beginning an exercise regimen and becoming more physically active, at risk firefighters like those assessed during the current investigation, require a physician’s clearance (1). Besides non-modifiable CVD risk factors such as age and family history, many other risk factors are modifiable with lifestyle alterations. Lifestyle modification such as enhanced physical activity, sleep, and dietary intake may be beneficial in reducing CVD risk among the firefighting profession. Performing 30 minutes or more of moderate intensity physical activity 5 or more d·wk^{-1}, or 20 minutes of vigorous intensity aerobic activity 3 or more min·wk^{-1} have been shown to promote health benefits such as increased aerobic fitness and performing 60-90 min·d^{-1} of moderate intensity exercise on most days of the week to reduce body weight (1, 13). Also, improving sleep duration to 7-8 hours per night may provide a reduction in mortality due to CVD related causes (115). Furthermore, the evidence obtained from this study warrants further research to gain objective measures of CVD risk in a larger sample of volunteer firefighters, as well as, give insight for the planning of future lifestyle interventions in firefighters.

CHAPTER IV

THE ASSOCIATION OF CARDIORESPIRATORY FITNESS AND BODY FAT WITH ARTERIAL STIFFNESS IN PROFESSIONAL FIREFIGHTERS

INTRODUCTION

Cardiovascular disease (CVD) plays a significant role in the health of firefighters and is the leading cause of on-duty fatalities in the fire service (32, 33, 34, 35, 36). According to Fahy and colleagues (36) over 1,000 firefighters died in the line of duty spanning the last decade, where 440 of those deaths were due to CVD. Furthermore, additional investigations have reported fatality rates due to CVD in the fire service to be as high as 50% of total on-duty deaths (33, 35). Post mortem reports from firefighter deaths due to CVD and related causes revealed many of the deceased had prior heart attacks, diagnosed and undiagnosed severe arteriosclerotic heart disease, diabetes, hypertension, hypercholesterolemia, obesity, family history of heart disease, and were cigarette smokers (33, 35, 84)

Identifying CVD risk factors and other factors associated with CVD, such as cardiorespiratory fitness (CRF) and obesity may provide practitioners with critical information in developing appropriate health-based interventions. Regarding cardiorespiratory fitness, The National Fire Protection Association (NFPA) (70) recommends that firefighters maintain a minimum cardiorespiratory fitness level of 12 METs (i.e., 42 $ml \cdot kg^{-1} \cdot min^{-1}$) in order to perform fire ground tasks. Baur and colleagues (4) examined the cardiorespiratory fitness levels among a cohort of over 900 firefighters and found that only 44% exceeded the 12 MET minimum recommendation. According to Baur et al. (4), the group achieving fitness levels above 12 METs possessed more favorable CVD risk profiles than the group with a fitness level below 12 METs.

Unpublished data from an investigation conducted by our research Laboratory (69) corroborate with Baur's (4) findings. Specifically, 83 professional firefighters were stratified into fit and unfit groups based on their cardiorespiratory fitness level (i.e., 12 MET capacity = 50th %ile). The unfit group displayed poorer CVD risk profiles including significantly greater levels of obesity, blood pressure, and HDL cholesterol. Furthermore, an investigation performed by Kodama et al. (52) found an inverse relationship between cardiorespiratory fitness and CVD profiles among adults. The researchers reported that those who had higher cardiorespiratory fitness levels possessed favorable triglyceride, cholesterol, and fasting glucose levels. In addition, it has also been suggested that improving maximal aerobic capacity by 1 MET ($3.5\ ml \cdot kg^{-1} \cdot min^{-1}$) is associated with a 15% reduction in CVD risk (52). Thus, cardiorespiratory fitness appears to be a critical outcome that is associated with firefighters' CVD risk and work capacity.

In addition to cardiorespiratory fitness, obesity has a profound effect on increased CVD risk (21, 23, 80). The prevalence of overweight and obesity among the fire service has been reported to be as high as 75% (80), which is greater than that seen in the general population (72). Increased levels of obesity have been associated with decreased vascular health leading to an increase in the risk of a cardiovascular event while on-duty (29). Firefighters with increased levels of obesity have also displayed altered blood lipid profiles, such as reduced HDL cholesterol, and increased LDL and total cholesterol (21, 23).

It is critical to have objective and field-based measures of CVD risk. One such measure includes arterial stiffness. Increased arterial stiffness is an indicator of increased CVD risk and has been shown to be an independent predictor of CVD (6, 64). Arterial stiffness can be assessed non-invasively by measuring the carotid-femoral pulse wave velocity (cfPWV). Carotid-femoral pulse wave velocity represents the speed the pulse wave travels between the carotid and femoral arteries. Increased arterial stiffness places an increased demand on the cardiovascular system. As large central arteries become stiff, left ventricular afterload increases (54, 57) and there is a reduction in coronary perfusion (46, 57). A chronic effect of increased afterload and reduced coronary blood flow may result in a rise in pulse pressure and systolic blood pressure producing left ventricular hypertrophy and heart failure (57).

Decreased cardiorespiratory fitness and increased obesity levels have been strongly correlated to increased arterial stiffness (9, 20, 90, 93, 106). However, no research has evaluated the association of cardiorespiratory fitness, independent of body fat, with arterial stiffness in a sample of professional firefighters. Furthermore, one investigation evaluated arterial stiffness at a single time point following the completion of fire ground tasks (31), as an increase in arterial stiffness has been observed immediately following supra-maximal anaerobic exercise (85). However, no research has systematically evaluated the time-course of arterial stiffness measures following maximal work in fit and unfit firefighters. Therefore, the purpose of this study was to evaluate the association of cardiorespiratory fitness, independent of body fat, with arterial stiffness at rest and following maximal work/exercise in professional firefighters. We hypothesized that, after controlling for fatness, the group of firefighters with lower levels of cardiorespiratory fitness would have greater resting and post-exercise cfPWV than the group of firefighters with higher levels of cardiorespiratory fitness.

SPECIFIC AIMS

The overall objective of this investigation was to determine the association of cardiorespiratory fitness with arterial stiffness measured at rest and following a maximal graded exercise test, in a sample of professional firefighters. To achieve this goal, the following aims were proposed:

1. Determine the association of cardiorespiratory fitness with arterial stiffness in firefighters at rest.
2. Determine the association of cardiorespiratory fitness with arterial stiffness in firefighters for 60 minutes post-exercise.

Delimitations

1) Professional male firefighters from the state of Kentucky between the ages of 18 – 50 years of age.
2)

Limitations

1) Subjects refrained from eating or drinking any caffeinated beverages at least 3 hours before laboratory testing.

2) Subjects gave a maximal effort during the maximal graded exercise test.

METHODS

Experimental Design and Subjects

The purpose of this investigation was to descriptively compare the association of cardiorespiratory fitness with arterial stiffness at rest and following maximal work in professional structural firefighters. The subjects were stratified into two groups based on their level of cardiorespiratory fitness. The measure of carotid-femoral pulse wave velocity (cfPWV) served as the dependent variable, whereas cardiorespiratory fitness (CRF), relative body fat, and time served as the independent variables.

Subjects

A convenience sample of 46 professional structural firefighters were recruited to participate in this investigation. To qualify for the study, subjects must have been a male professional structural firefighter between 18 and 50 years of age. All subjects were free of cardiovascular disease and considered at low to moderate cardiovascular disease (CVD) risk according to the American College of Sports Medicine (1). All subjects provided written informed consent after a detailed explanation of the investigation's aims, benefits, and risks were provided. Additionally, the subjects were informed that their participation in the study would not affect their employment status with the fire department or any associated unions and that they were free to withdraw from the study at any time. All of the study's procedures were approved by the University's Institutional Review Board.

Cardiorespiratory Fitness Grouping

The firefighters were stratified into two groups based on their cardiorespiratory fitness level at the time of testing. Cardiorespiratory fitness was determined from a maximal treadmill graded exercise test (GXT) performed wearing personal protective equipment (PPE) and a self-contained breathing apparatus (SCBA; minus the mask), but breathing room air. The National Fire Protection Association (70) recommends a minimum CRF of 42 $ml \cdot kg^{-1} \cdot min^{-1}$ in order to successfully complete fire ground tasks. However, the effect of PPE alone on CRF has been found to decrease maximal oxygen consumption by 4% (59). When assessing firefighter CRF wearing PPE and breathing from the SCBA respirator, the decrease in maximal oxygen uptake was found to be as large as 17% – 18% (22, 60). The largest reduction in maximal oxygen uptake can be attributed to decreased ventilation at a maximal workload caused by an increased work of breathing due to increased expiratory resistance from the SCBA regulator (26). Therefore, after taking into account the reduction in maximal oxygen consumption due to the effect of the PPE and SCBA respirator, firefighters would need an actual cardiorespiratory fitness of ≥ 48.3 $ml \cdot kg^{-1} \cdot min^{-1}$ in order to meet the minimum standard suggested by the NFPA (70) to complete fire ground tasks. A corrected cardiorespiratory fitness level was used for grouping purposes in order to account for the effect of PPE and SCBA to make a more occupationally relevant CRF stratification threshold. Subjects with a maximal CRF < 48.3 $ml \cdot kg^{-1} \cdot min^{-1}$ were classified as "unfit" and subjects with a maximal CRF of ≥ 48.3 $ml \cdot kg^{-1} \cdot min^{-1}$ were classified as "fit".

Procedures

Subjects were required to partake in one testing session lasting approximately 2.5 hours. Subjects were instructed to refrain from eating or drinking beverages containing caffeine at least 3 hours before testing. Upon arrival to the Laboratory, each subject provided written informed consent to participate in the study.

Questionnaires

Subjects were screened for participation by completing the Physical Activity Readiness-Questionnaire (PAR-Q). Any positive responses given on the PAR-Q caused exclusion from the investigation. Next, all subjects completed a Medical History Questionnaire in order to identify any subjects that had any signs or symptoms of, or were diagnosed with cardiovascular, metabolic, or pulmonary diseases. Finally, subjects completed the International Physical Activity Questionnaire (IPAQ) in an attempt to assess self-reported weekly physical activity levels.

Anthropometric Measurements

Next, anthropometric measures of the body were taken. Standing height was measured without shoes (to the nearest 0.1 cm) using a wall mounted stadiometer (SECA, Chino, CA). Body mass was measured wearing a cotton t-shirt and athletic shorts (to the nearest 0.1 kg) via a calibrated digital scale (American Scale, Louisville, KY). Three circumference measurements were taken (to the nearest 0.1 cm) at the waist, abdomen, and hip according to the American College of Sports Medicine (1) guidelines. The waist circumference measurement was located at the narrowest portion of the torso. The abdominal circumference was located directly at the level of the umbilicus. The hip circumference was located at the maximal protuberance of the gluteus maximus. All circumference measurements were taken after a natural exhalation and in rotational order. Any circumference site measurements that were not within 1.0 cm were repeated until 2 trials were within 1.0 cm. All circumference measures were taken directly on the skin except for the hip measurement, which was taken over the athletic shorts. The test-retest reliability of these measurements in this sample ranged from $r = 0.997\text{-}.999$

Body Composition Assessment

Body composition was measured with a multi-frequency bioelectric impedance analyzer (BIA; Bodystat Quadscan 4000; Bodystat Ltd., Isle of Man, British Isles). Specifically, whole-body resistance was measured while the subject rested on a non-conductive surface in a supine position with the arms and legs slightly abducted from the midline of the body. Two sensor surface electrodes were positioned on the right side of the body. The first sensor electrode bisected the head of the ulna of the right wrist, while the second sensor electrode bisected the medial and lateral malleoli of the right foot. The source surface electrodes were positioned on the right hand and right foot at the base of the metacarpal-phalangeal joint. A series of low-level electrical currents (5, 50, 100, and 200 Khz) were employed directly to the distal source electrodes and the voltage drop due to impedance was detected by the sensor electrodes located proximally. This measurement was performed twice per subject. The manufacturer's proprietary prediction equation for adult male subjects was utilized in order to estimate the subjects' body composition (percent fat, fat mass and fat-free mass). The validity of the percent fat measurement (proprietary body fat equation) compared to DXA has been reported to be $r = 0.88$ (100). The test-retest reliability of this measurement in this sample was $r = 1.000$

Pulse Wave Analysis Assessment

Before assessment of cfPWV, subjects were prepared with a 3-lead electrocardiograph (ECG). Any hair present on the subjects' chest was shaved and the skin was cleaned with an alcohol swab in order to remove skin oils and excess hair. The subject rested for 10 minutes in a supine position in a temperature controlled room at

25°C. Palpation of the carotid and femoral arteries were performed and each site was marked with a permanent marker for repeated measures at each site. Carotid-femoral pulse wave velocity was assessed utilizing the SphygomCor system (ArtCor, Sydney, Australia) via transcutaneous tonometry of the carotid and femoral arteries with simultaneous ECG recording. Using the Sphygomocor system, pressure waves were recorded sequentially from the two sites while transit times were recorded using the incorporated ECG. The test-retest reliability of these measurements in this sample was $r = 0.875$. The pressure wave transit time was calculated in relation to the ECG by taking the time between the R-wave and the proximal pulse at the carotid artery subtracted by the time between the R-wave and the distal pulse at the femoral artery. The measurements were taken between the two sites in immediate fashion so minimal variation in heart rate occurred. A small change in heart rate ($<5\ \text{b}\cdot\text{min}^{-1}$) will have little to no effect on measured pulse transit time (54). The distance in which the pulse wave traveled was measured over the body with a fiberglass measuring tape and recorded to the nearest millimeter. The cfPWV was calculated and presented in meters per second. Transcutaneous tonometry was also applied at the radial artery in order to estimate central aortic pressure with the use of the validated transfer function (14). Pressure waveforms were measured until an acceptable recording was obtained (operator index >80%). Following the maximal graded exercise test, arterial stiffness was measured immediately after (6.1 ± 0.9 min), followed by repeated measurements taken every 10 minutes starting at 10 minutes post-exercise and continued for 60 minutes post-exercise.

Cardiorespiratory Fitness Assessment

Before the measurement of maximal CRF was assessed, subjects were prepared with a 12-lead ECG (Nihon Kohden, Model ECG-1550A, Tokyo, Japan). Any hair present on the subjects' chest was shaved and the skin was cleaned with an alcohol swab in order to remove skin oils and excess hair. Subjects then rested in a seated position while the 12-lead ECG was assessed. If any abnormal rhythms and/or waveforms were present, the physician serving on the protocol was contacted for either clearance or termination of the test (no tests were terminated during the duration of the study). If subjects were cleared for participation, the ECG leads were wrapped tightly against the skin using an elastic bandage in order to secure the leads to the chest and minimize lead noise during exercise. All subjects wore a cotton t-shirt, exercise shorts, and athletic shoes under their PPE (turnout coat, pants, hood, gloves, and helmet). All subjects also wore the same SCBA harness and Scott Air-Pac (with full 30 minute fiber composite air cylinder; Scott Health and Safety, Monroe, NC). The SCBA regulator was not be used to breathe, simply carried on a harness to simulate firefighter load carriage. Instead, ambient air was inhaled via the Hans Rudolf 2700 series low resistance breathing valve (Hans Rudolf, Kansas City, Missouri) attached to the metabolic cart during the graded exercise test. All tools were removed from coat and pant pockets to standardize the weight of the PPE and SCBA across all subjects (19.11 ± 1.33 kg).

Subjects' maximal aerobic capacity was obtained using the TrueMax 2400 computerized metabolic cart (ParvoMedics, Salt Lake City, Utah) via a maximal GXT protocol using a treadmill (Star Trac, Unisen Inc., Irvine, CA). The GXT utilized increases in treadmill grade to simulate stair climbing tasks as are regularly performed by firefighters (Table 4-1).

Table 4-1. Maximal Graded Exercise Protocol.

Stage	Minutes	Percent Grade	Velocity ($m \cdot min^{-1}$)
1	1	0	99.2
2	2	1.5	99.2
3	3	3	99.2
4	4	4.5	99.2
5	5	6	99.2
6	6	7.5	99.2
7	7	9	99.2
8	8	10.5	99.2
9	9	12	99.2
10	10	13.5	99.2
11	11	15	99.2
12	12	16.5	99.2
13	13	16.5	110.0
14	14	16.5	118.0
15	15	16.5	126.1
16	16	16.5	134.1

Calibration of gas analyzers was performed prior to each test using a calibration gas mixture of known gas concentrations (3.99% CO_2, 15.98% O_2, N_2 balance). The pneumotachometer (Hans Rudolf, Kansas City, Missouri) was calibrated according to the manufacturer specifications using a 3 L air syringe (Hans Rudolf 5530 series). Before the start of the exercise protocol, subjects completed a three minute warm-up period walking at 80.5 $m \cdot min^{-1}$. Following the warm-up participants walked at 99.2 $m \cdot min^{-1}$ with linear increases in treadmill grade every minute until volitional fatigue was reached and/or subjects achieved two of the following parameters to reach VO_2 peak: oxygen consumption failed to increase after an increase in exercise intensity, subjects' heart rate failed to increase with an increase in work rate, heart rate met or exceeded age adjusted heart rate maximum, RPE of ≥ 17, or respiratory exchange ratio (RER) met or exceeded 1.10. All subjects reached VO_2 peak. Exercising ECG and heart rate were measured continuously with the 12 lead ECG machine while a rating of perceived exertion (Borg scale 6 – 20) was recorded each minute during the treadmill protocol. American College of Sports Medicine guidelines for exercise testing were followed (1).

Statistical Analysis

Basic statistics (mean ± standard deviations) were used to describe demographics and outcome variables. T-tests were performed to determine if differences existed between groups in anthropometric and cardiovascular measurements. Fisher's coefficient of skewness (skewness/standard error of skewness) was performed to assess the normality of cfPWV variables. All variables yielded a skewness coefficient less than the absolute value of 1.96, thus were considered to be normally distributed. Pearson Product Moment Correlations were performed to evaluate the relationship between anthropometric and cardiovascular measures as arterial stiffness has been shown to be associated with fitness, fatness, blood pressure, and age. A repeated measures ANCOVA (fitness stratification x time) was utilized to determine if there were differences in cfPWV within or between groups over time. Relative body fat was significantly different between fitness strata and significantly correlated to arterial stiffness. Therefore, relative body fat served as a covariate in the ANCOVA. T-tests were used in the post-hoc analysis to determine if differences existed between groups in cfPWV at each of the 8 tested time points. All analyses were performed using IBM SPSS (version 22, New York, United States) statistical software. Two-tailed probability values of < 0.05 were considered statistically significant.

RESULTS

A total of 46 male professional firefighters participated in the investigation. The subjects' ages ranged from 22 to 50 years with firefighting experience ranging from 1 to 25 years. Table 4-2 displays the descriptive characteristics between firefighter groups. There was no difference in age between the fitness groups, but the unfit group had significantly greater measurements of body weight, BMI, waist circumference, abdominal circumference, hip circumference, and percent body fat compared to the fit group ($p \leq 0.002$). The fit group had higher levels of cardiorespiratory fitness and time on treadmill compared to the unfit group ($p \leq 0.003$). There was no difference between groups in the weight of the PPE worn during the maximal graded exercise test.

Table 4-2. Descriptive comparison between cardiorespiratory fitness groups of 46 male professional firefighters (Mean ± SD).

	Fit (n = 23)	Unfit (n = 23)	p-value
Age (yr)	34.09 ± 7.73	38.35 ± 7.00	0.057
Firefighting experience (yr)	7.43 ± 5.28	11.70 ± 7.37	0.029*
Height (cm)	179.14 ± 7.08	181.47 ± 6.51	0.252
Weight (kg)	85.69 ± 10.53	99.12 ± 14.32	0.001*
BMI ($kg \cdot m^{-2}$)	26.66 ± 2.60	30.14 ± 4.11	0.002*
Weight of PPE (kg)	18.76 ± 0.71	19.45 ± 1.68	0.075
Weight in PPE (kg)	104.39 ± 10.58	118.87 ± 14.51	0.001*
Waist Circumference (cm)	87.63 ± 5.92	100.53 ± 10.20	<0.001*
Abdominal Circumference (cm)	90.32 ± 6.88	103.28 ± 10.93	<0.001*
Hip Circumference (cm)	102.00 ± 6.22	108.29 ± 6.97	0.002*
Percent Fat (%)	14.06 ± 4.16	21.03 ± 5.79	<0.001*
Fat Mass (kg)	12.29 ± 4.59	21.49 ± 8.26	<0.001*
Fat-free Mass (kg)	73.40 ±7.48	77.62 ± 7.57	0.063
VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.62 ± 3.53	40.73 ± 5.59	<0.001*
VO_{2peak} ($L \cdot min^{-1}$)	4.60 ± 0.65	4.01 ± 0.63	0.003*
RER at VO_2 peak	1.07 ± 0.04	1.07 ± 0.04	0.791
RPE	18.52 ± 0.90	18.22 ± 0.90	0.258
Heart Rate Maximum ($b \cdot m^{-1}$)	186.65 ± 7.73	181.74 ± 7.97	0.040*
Time on Treadmill (s)	731.30 ±86.72	537.39 ± 117.91	<0.001*

Fit group: $VO_{2peak} \geq 48.3\ ml \cdot kg^{-1} \cdot min^{-1}$; Unfit group: $VO_{2peak} < 48.3\ ml \cdot kg^{-1} \cdot min^{-1}$

*p < 0.05, *t*-test between Fit and Unfit groups of professional and firefighters.

Minimum and maximum age for fit group: 22-50 yr; Unfit group: 26-50 yr.

CRF: Cardiorespiratory Fitness; RER: Respiratory Exchange Ratio; PPE: Personal protective equipment; BMI: Body mass index; RPE: Rating of perceived exertion.

A descriptive comparison of the resting cardiovascular measurements between fit and unfit firefighters is presented in Table 4-3. Resting cfPWV was significantly lower in the fit firefighters ($p < 0.001$). Most resting measures of pressure (except pulse pressure) including both brachial and aortic were significantly less in the fit group compared to the unfit group ($p \leq 0.03$). The fit group also had significantly lower resting heart rate and brachial and aortic mean arterial pressure compared to the unfit group ($p \leq 0.02$).

Table 4-3. Resting cardiovascular measurements between cardiorespiratory fitness groups of 46 male professional firefighters (Mean ± SD).

	Fit (n = 23)	Unfit (n = 23)	Rel. diff (%)	p-value
cfPWV ($m \cdot s^{-1}$)	6.09 ± 0.69	7.28 ± 1.35	17.80	<0.001*
Systolic Blood Pressure (mmHg)	117.57 ± 9.42	125.39 ± 12.19	6.44	0.020*
Diastolic Blood Pressure (mmHg)	74.87 ± 7.11	80.26 ± 8.97	6.95	0.029*
Pulse Pressure (mmHg)	42.70 ± 8.41	45.13 ± 6.76	5.53	0.285
Mean Arterial Pressure (mmHg)	88.96 ± 6.89	95.15 ± 9.63	6.72	0.016*
Heart Rate ($b \cdot min^{-1}$)	60.65 ± 6.49	70.45 ± 9.70	14.95	<0.001*
Aortic Systolic Pressure (mmHg)	102.22 ± 8.63	109.87 ± 11.79	7.21	0.016*
Aortic Diastolic Pressure (mmHg)	75.48 ± 7.05	81.04 ± 8.95	7.10	0.024*
Aortic Pulse Pressure (mmHg)	26.74 ± 5.14	28.83 ± 5.19	7.52	0.178
Aortic Mean Arterial Pressure (mmHg)	84.30 ± 7.21	90.56 ± 9.68	7.16	0.017*

$^{*}p < 0.05$, *t*-test between Fit and Unfit groups of professional firefighters.
cfPWV: Carotid to femoral pulse wave velocity; Rel. diff.: relative difference between groups calculated by the (difference/average).

Bivariate correlations between arterial stiffness versus demographic, anthropometric and cardiovascular variables are presented in Table 4-4. There were significant negative correlations between relative and absolute VO_{2peak} versus cfPWV (relative VO_{2peak}: $r = –0.59$, $p < 0.001$; absolute VO_{2peak}: $r = –0.30$, $p = 0.041$). This relationship suggests that as cardiorespiratory fitness increases cfPWV decreases. There was a significant positive correlation between relative and absolute fat and cfPWV (relative body fat: $r = 0.60$, $p < 0.001$; absolute body fat: $r = 0.56$, $p < 0.001$), meaning that as percent fat and fat-mass decreases cfPWV decreases. There was a significant negative relationship between relative VO_{2peak} and percent fat ($r = – 0.70$, $p < 0.001$), meaning that as percent fat decreases cardiorespiratory fitness increases. Weaker significant positive relationships were also seen between cfPWV versus systolic blood pressure, diastolic blood pressure, aortic systolic blood pressure, and aortic diastolic blood pressure.

Table 4-4. Correlation matrix of carotid-femoral pulse wave velocity versus demographic, anthropometric and cardiovascular measures in 46 male professional firefighters.

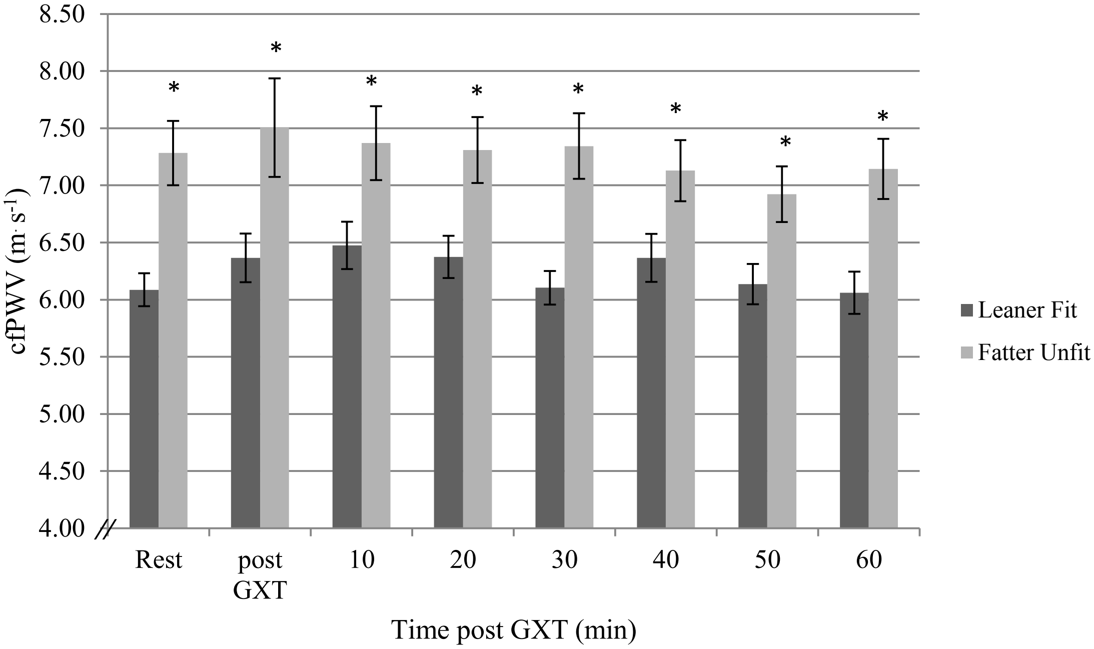
	Age	FF Years	BMI	WC	% Fat	SBP	DBP	Aortic SBP	Aortic DBP	VO_{2peak}
Age										
FF Years	0.81^*									
BMI	0.16	0.21								
WC	0.34^*	0.37^*	0.88^*							
% Fat	0.36^*	0.36^*	0.83^*	0.93^*						
SBP	0.13	0.09	0.53^*	0.53^*	0.51^*					
DBP	0.29^*	0.30^*	0.67^*	0.67^*	0.62^*	0.75^*				
Aortic SBP	0.30^*	0.25	0.58^*	0.59^*	0.56^*	0.93^*	0.88^*			
Aortic DBP	0.31^*	0.32^*	0.68^*	0.69	0.64	0.75^*	0.99^*	0.89^*		
VO_{2peak}	-0.34^*	-0.43^*	-0.71^*	-0.71^*	-0.70^*	-0.36^*	-0.42^*	-0.43^*	-0.43^*	
cfPWV	0.52^*	0.40^*	0.49^*	0.58^*	0.60^*	0.30^*	0.37^*	0.36^*	0.38^*	-0.59^*

$^*p < 0.05$.

FF Years: Years as a professional firefighters; W.C.: Waist Circumference; % Fat: Percent Fat; SBP: Resting systolic blood pressure; DBP: Resting diastolic blood pressure; Aortic SBP: Resting aortic systolic blood pressure; Aortic DBP: Resting aortic diastolic blood pressure; VO_{2peak}: $\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$; cfPWV: resting carotid to femoral pulse wave velocity ($\mathrm{m \cdot s^{-1}}$).

A comparison of cfPWV between fitness groups at rest and post-exercise is illustrated in Figure 4-1. The ANCOVA analysis revealed that there was a significant effect of relative fat on arterial stiffness but not a significant effect of CRF on arterial stiffness. This indicated that the difference in relative fatness between groups was responsible for the difference in cfPWV. Post-hoc analysis indicated that the leaner fit group had a significantly lower cfPWV compared to the fatter unfit group at every time point by nearly 1.0 $m \cdot s^{-1}$ ($p \leq 0.036$). There was no effect of time on cfPWV.

Figure 4-1. Descriptive comparison of cardiorespiratory fitness and fatness on carotid-femoral pulse wave velocity (cfPWV) at rest and post-exercise in 46 male professional firefighters.



*$p < 0.05$, *t*-test between leaner Fit and fatter Unfit groups of professional firefighters. Error bars represent standard error.

The repeated measures ANCOVA analysis (Table 4-5) also determined there was no main effect for time or group x time interaction ($p \geq 0.05$), meaning there was no change in cfPWV within groups post-exercise.

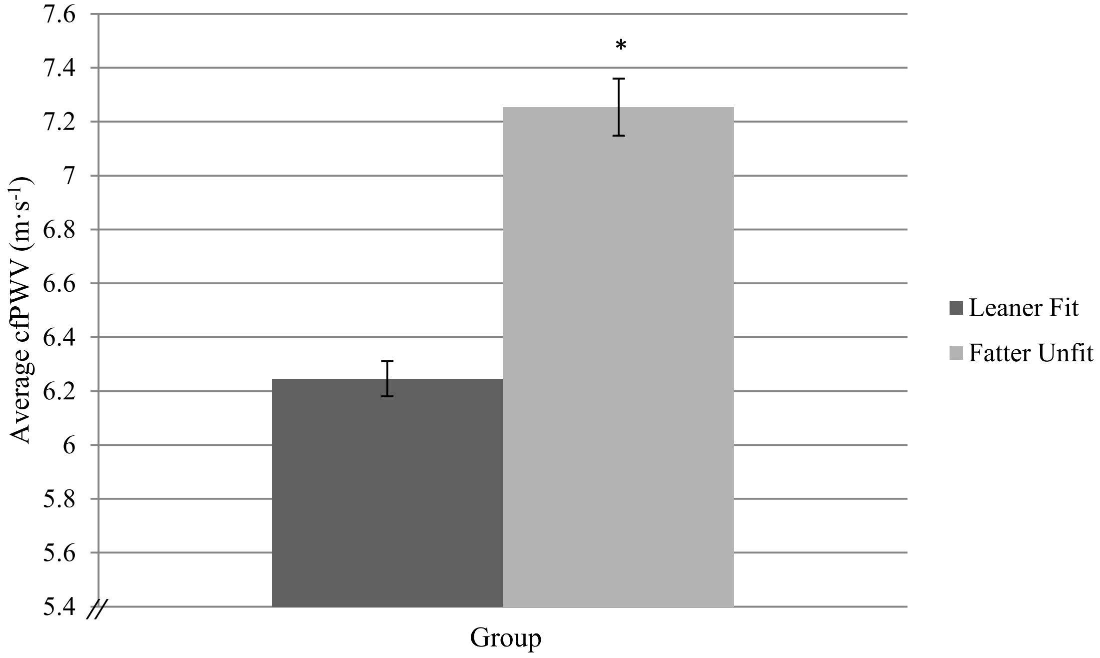
Table 4-5. Results of the repeated measures ANCOVA evaluating the main effects of fitness by time while covarying for percent fat in 46 male professional firefighters.

	F	sig.	Effect size	Power
Within Subjects:				
Time	0.553	0.794	0.013	0.239
Time x Percent fat	0.508	0.828	0.012	0.220
Time x Fitness stratification	0.393	0.906	0.010	0.175
Between Subjects:				
Percent Fat	17.24	<0.001*	0.296	0.982
Fitness stratification	0.484	0.490	0.012	0.104

*$p < 0.05$

Because there was not a main effect of time on arterial stiffness, cfPWV taken at the eight time points were collapsed and averaged and compared between groups. The average difference between fitness groups in cfPWV for all time points was 1.004 m·s^{-1} (Leaner fit group = 6.25 m·s^{-1}; Fatter unfit group = 7.25 m·s^{-1}; Figure 4-2).

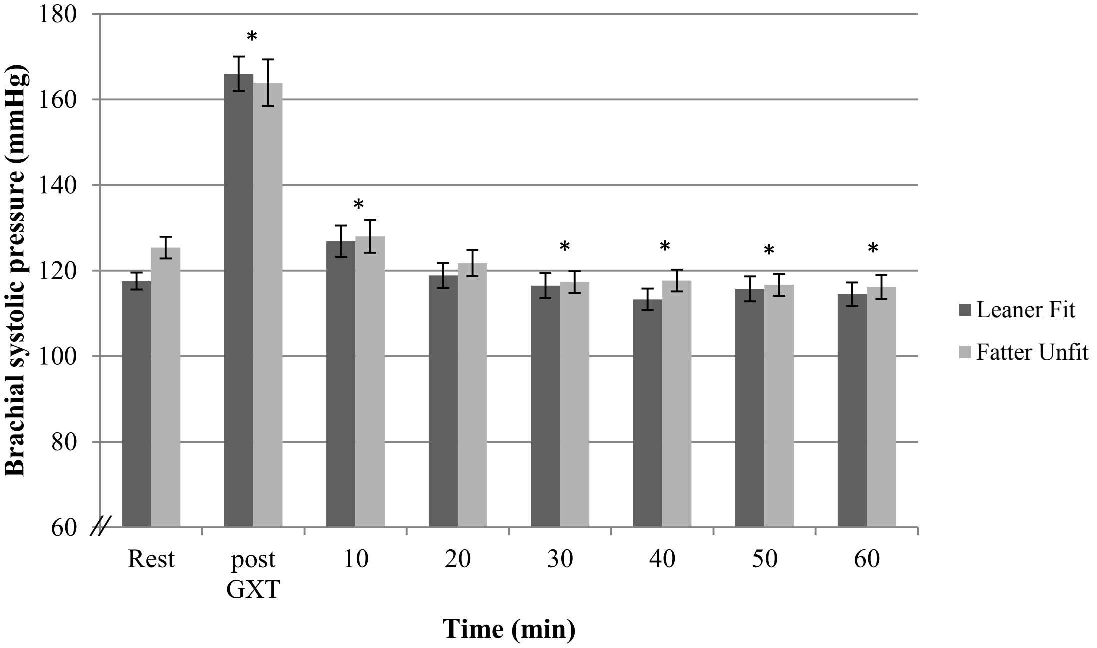
Figure 4-2. Average cfPWV across all resting and post-exercise time points between cardiorespiratory fitness groups.



*$p < 0.05$
Error bars represent standard error.

A comparison of brachial systolic blood pressure between fitness groups at rest and post-exercise is illustrated in Figure 4-3. A repeated measure ANOVA showed that there was no effect of fitness stratification ($p = 0.581$) on brachial systolic pressure but a significant effect of time ($p < 0.001$) within the group post-exercise. Within the group, brachial systolic pressure was significantly higher post GXT and 10 minute post-exercise compared to rest. Conversely, brachial systolic pressure was significantly lower 30, 40, 50, and 60 minutes post-exercise compared to rest.

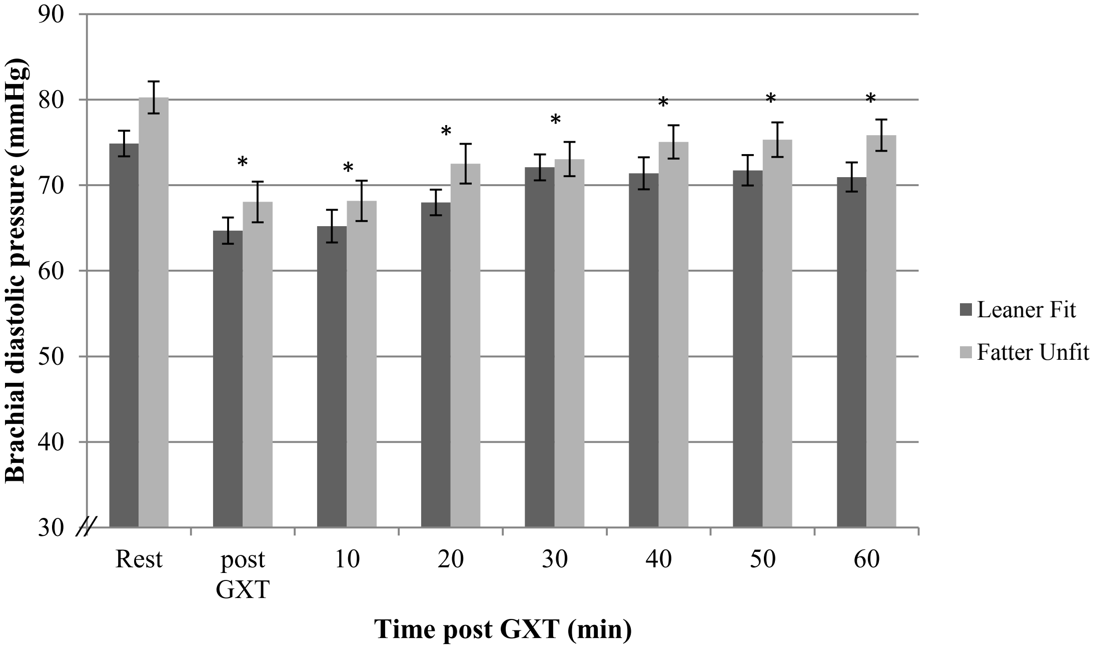
Figure 4-3. Descriptive comparison of cardiorespiratory fitness and fatness on brachial systolic blood pressure at rest and post-exercise in 46 male professional firefighters.



$^{*}p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of brachial diastolic blood pressure between fitness groups at rest and post-exercise is illustrated in Figure 4-4. A repeated measure ANOVA showed that there was no effect of fitness stratification (p = 0.114) on brachial diastolic pressure but a significant effect of time (p < 0.001) within the group post-exercise. Within the group, brachial diastolic pressure was significantly lower post GXT, 10, 20, 30, 40, 50 and 60 minutes post-exercise compared to rest.

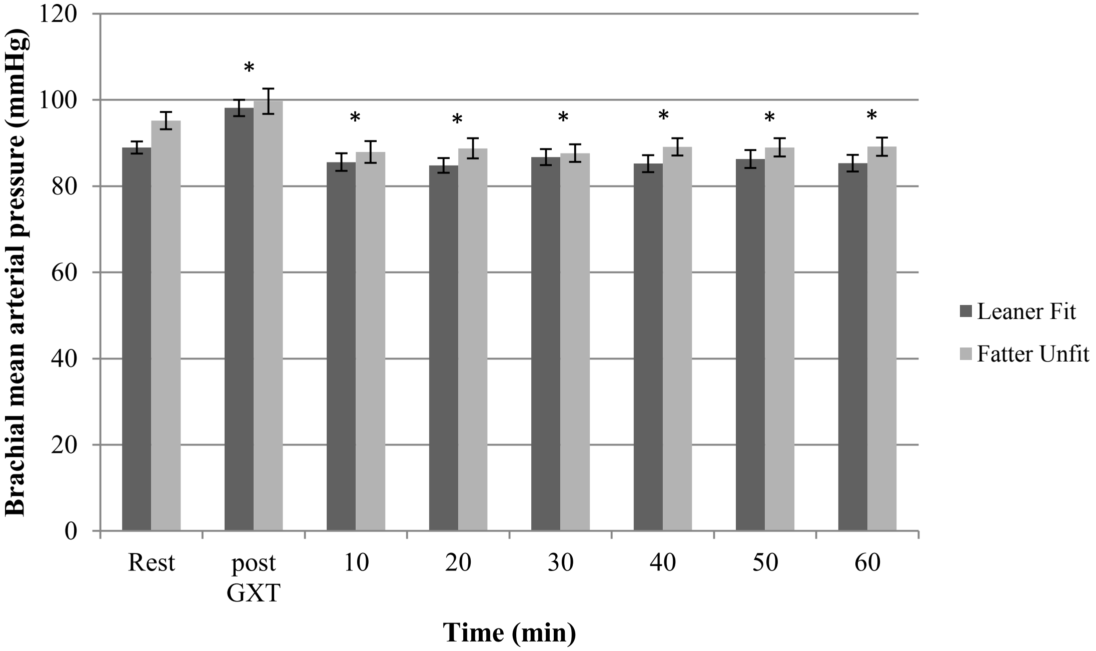
Figure 4-4. Descriptive comparison of cardiorespiratory fitness and fatness on brachial diastolic blood pressure at rest and post-exercise in 46 male professional firefighters.



$^{*}p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of brachial mean arterial pressure between fitness groups at rest and post-exercise is illustrated in Figure 4-5. A repeated measure ANOVA showed that there was no effect of fitness stratification (p = 0.238) on brachial mean arterial pressure but a significant effect of time (p < 0.001) within the group post-exercise. Within the group, brachial mean arterial pressure was significantly higher post GXT compared to rest. Conversely, brachial mean arterial pressure was significantly lower 10, 20, 30, 40, 50, and 60 minutes post-exercise compared to rest.

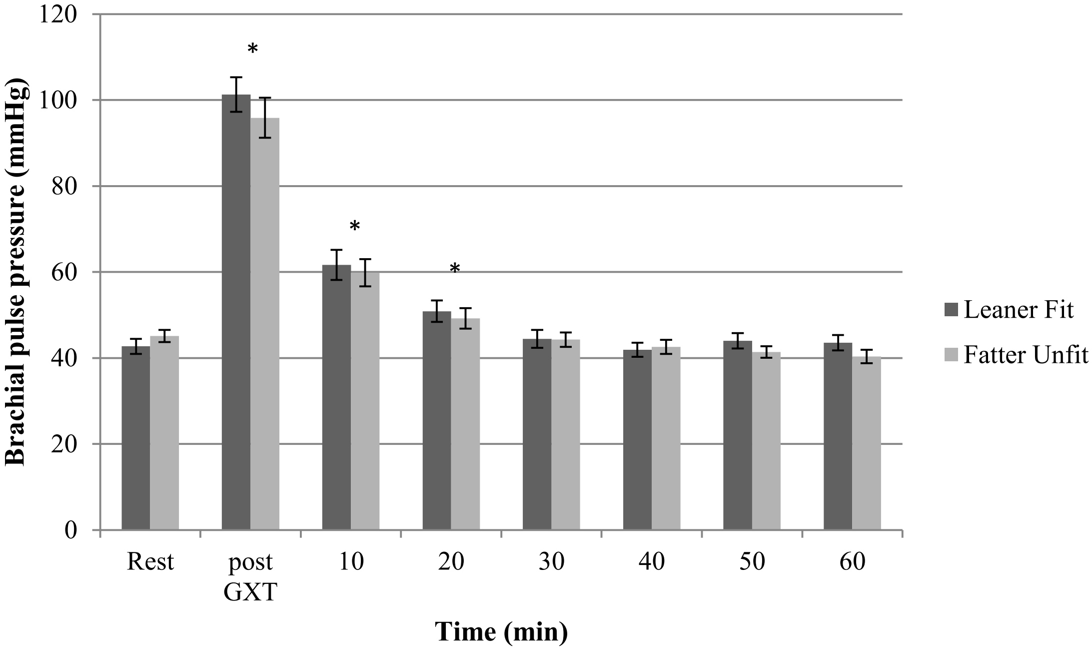
Figure 4-5. Descriptive comparison of cardiorespiratory fitness and fatness on brachial mean arterial pressure at rest and post-exercise in 46 male professional firefighters.



$^{*}p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of brachial pulse pressure between fitness groups at rest and post-exercise is illustrated in Figure 4-6. A repeated measure ANOVA showed that there was no effect of fitness stratification (p = 0.577) on brachial pulse pressure but a significant effect of time (p < 0.001) within fitness groups post-exercise. Within the group, brachial pulse pressure was significantly higher post GXT, 10, and 20 minutes post-exercise compared to rest.

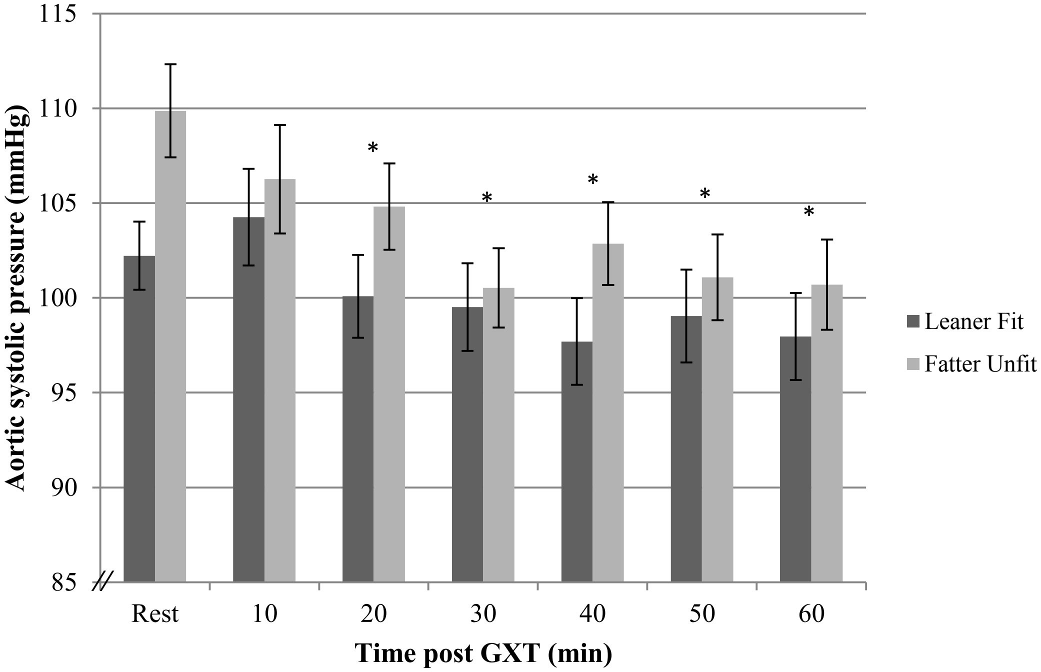
Figure 4-6. Descriptive comparison of cardiorespiratory fitness and fatness on brachial pulse pressure at rest and post-exercise in 46 male professional firefighters.



*p < 0.007, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of aortic systolic blood pressure between fitness groups at rest and post-exercise is displayed in Figure 4-7. A repeated measure ANOVA showed that there was no effect of fitness stratification (p = 0.191) on aortic systolic pressure but a significant effect of time (p < 0.001) within the group post-exercise. Within the group, aortic systolic pressure was significantly lower 20, 30, 40, 50, and 60 minutes post-exercise compared to rest.

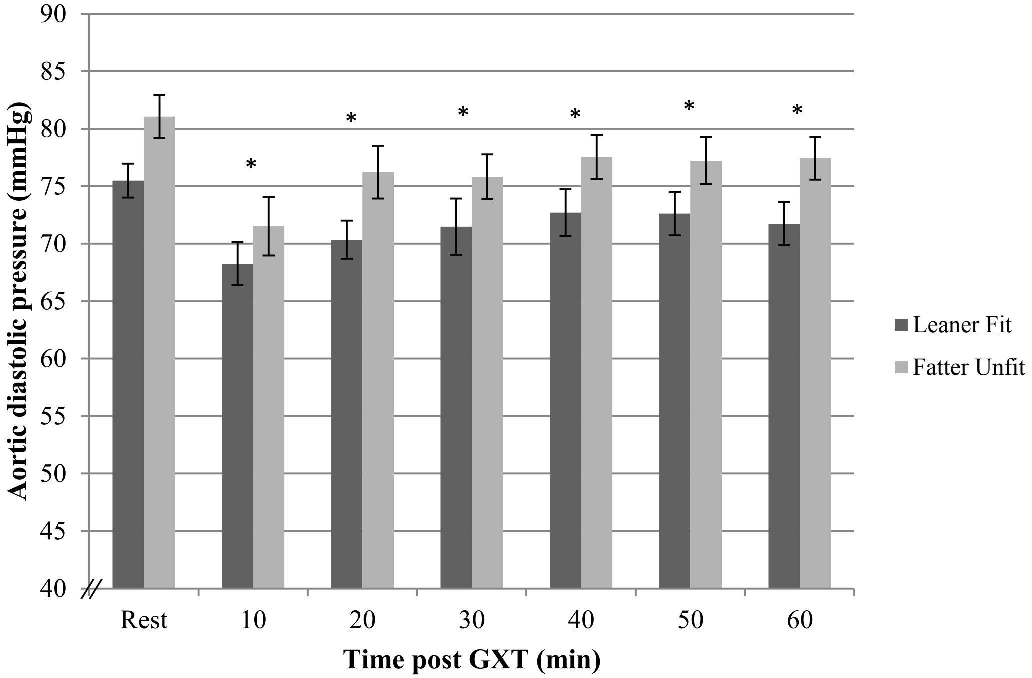
Figure 4-7. Descriptive comparison of cardiorespiratory fitness and fatness on aortic systolic blood pressure at rest and post-exercise in 46 male professional firefighters.



$^*p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of aortic diastolic blood pressure between groups at rest and post-exercise is displayed in Figure 4-8. A repeated measure ANOVA showed that there was an effect of fitness stratification ($p = 0.042$) on aortic diastolic pressure and a significant effect of time ($p < 0.001$) within the group post-exercise. Within the group, aortic diastolic pressure was significantly lower 10, 20, 30, 40, 50, and 60 minutes post-exercise compared to rest.

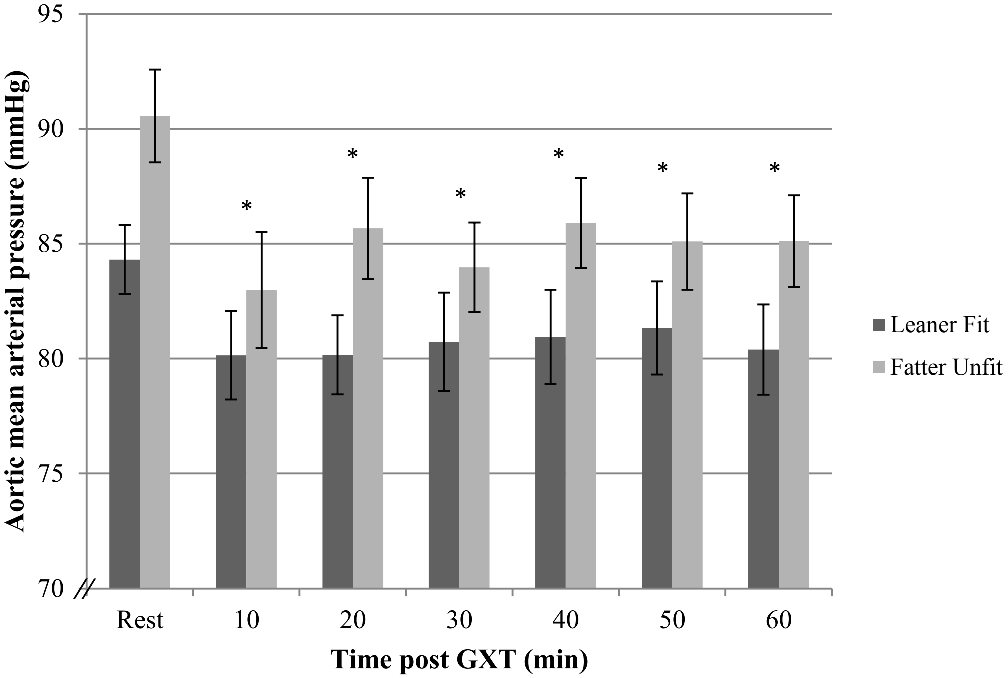
Figure 4-8. Descriptive comparison of cardiorespiratory fitness and fatness on aortic diastolic blood pressure at rest and post-exercise in 46 male professional firefighters.



$^{*}p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison of aortic mean arterial pressure between groups at rest and post-exercise is displayed in Figure 4-9. A repeated measure ANOVA showed that there was no effect of fitness stratification ($p = 0.067$) on aortic mean arterial pressure and a significant effect of time ($p < 0.001$) within the group post-exercise. Within the group, aortic mean arterial pressure was significantly lower 10, 20, 30, 40, 50, and 60 minutes post-exercise compared to rest.

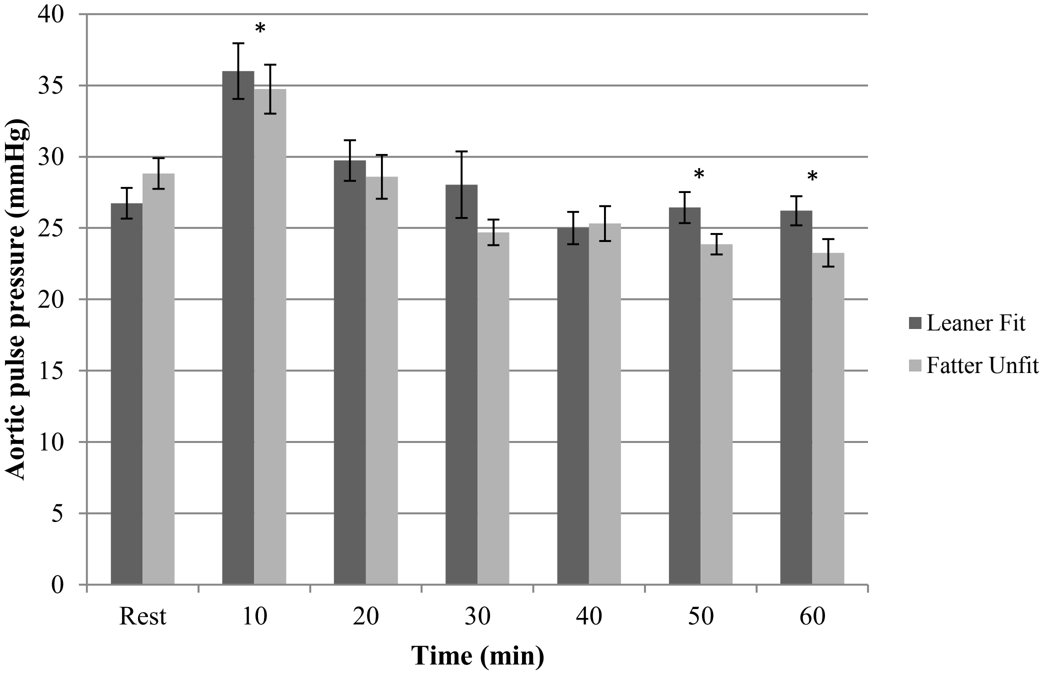
Figure 4-9. Descriptive comparison of cardiorespiratory fitness and fatness on aortic mean arterial pressure at rest and post-exercise in 46 male professional firefighters.



$^{*}p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

A comparison in aortic pulse pressure between groups at rest and post-exercise is displayed in Figure 4-10. A repeated measure ANOVA showed that there was no effect of fitness stratification ($p = 0.415$) on aortic pulse pressure and a significant effect of time ($p < 0.001$) within the group post-exercise. Within the group, aortic pulse pressure was significantly higher 10 minutes post-exercise compared to rest. Conversely, aortic pulse pressure was significantly lower 50 and 60 minutes post-exercise compared to rest.

Figure 4-10. Descriptive comparison of cardiorespiratory fitness and fatness on aortic pulse pressure at rest and post-exercise in 46 male professional firefighters.



[*] $p < 0.007$, *t*-test between rest and post-exercise measurements.
Error bars represent standard error.

DISCUSSION

The purpose of this investigation was to determine the association of cardiorespiratory fitness with arterial stiffness in firefighters at rest and post-exercise. We hypothesized that firefighters with higher levels of CRF would have lower cfPWV measures at rest and post-exercise compared to firefighters with lower levels of CRF. Our primary finding was that, after controlling for the confounding effect of relative body fat, there was no main effect for CRF on arterial stiffness. That is, there was a significant effect of relative fat on arterial stiffness but a non-significant effect for the CRF grouping. This indicated that the difference in relative fatness between groups produced the difference in cfPWV. The post-hoc analysis indicated that the leaner fit group had a significantly lower cfPWV compared to the fatter unfit group at every time point by an average of 1.004 $m \cdot s^{-1}$ (14.9 % lower; $p \leq 0.036$).

Hansen and colleagues (43) examined cfPWV in adults ranging from 40-70 years of age. The researchers demonstrated that for each standard deviation increment in cfPWV (3.4 $m \cdot s^{-1}$), the risk of a cardiovascular event increased by nearly 20%. Additionally, cfPWV was a significant predictor of cardiovascular complications above and beyond traditional CVD risk factors such as age, current cigarette smoking, and BMI. Mattace-Raso et al. (64) supported these findings as they investigated the role of arterial stiffness on risk for coronary heart disease using a longitudinal model including nearly 3000 adult subjects. Arterial stiffness, measured via cfPWV was found to be a strong independent predictor of coronary heart disease in apparently healthy adults. The significant difference in average cfPWV of 1.004 $m \cdot s^{-1}$ (fit = 6.25 $m \cdot s^{-1}$ vs. unfit = 7.25 $m \cdot s^{-1}$) between fitness groups in the current study may suggest an elevated CVD risk among the unfit group. It has been demonstrated that resting cfPWV measures $< 6.5\ \mathrm{m \cdot s^{-1}}$ (101) and a reduction in cfPWV of $1\ \mathrm{m \cdot s^{-1}}$ (109) may reduce CVD risk and the likelihood of experiencing a cardiovascular event and cardiovascular mortality, respectively.

An increase in arterial stiffness assessed via cfPWV has also been shown to be a strong predictor of cardiac events in many other investigations (6, 58, 66, 73, 101, 109). Mitchell et al. (66) reported a strong association ($p<0.05$) between cfPWV and CVD risk, stating that a higher cfPWV was associated with a 48% increase in CVD risk. However, adults considered at the highest risk for a major cardiovascular event were those with cfPWV $\geq 11.8\ \mathrm{m \cdot s^{-1}}$. Of the adults tested in the current investigation, only 8% of firefighters in the unfit group had cfPWV measurements above $11.8\ \mathrm{m \cdot s^{-1}}$, indicating a heightened level of risk for those individuals. Conversely, no subjects in the fit group had measures above this threshold.

In the current investigation the fatter unfit firefighters demonstrated greater arterial stiffness at rest and post-exercise. In addition, there was a significant positive correlation between relative body fat (percent fat) and resting cfPWV ($r = 0.60$, $R^2 = 0.36$, $p < 0.001$), suggesting that cfPWV was elevated as percent fat increased. This finding is in agreement with Wildman et al. (113) who reported a significant positive correlation ($r = 0.37$, $R^2 = 0.14$, $p < 0.001$) between cfPWV and obesity in adult subjects ranging in age from 22- 40 years. The main finding from the investigation by Wildman and colleagues (113) was that measures of body fatness were strong independent predictors of aortic stiffness. The researchers also suggested that excess body fatness in adults as young as 20 years exhibited advancements in arterial aging. Scuteri and coworkers (90) also found a positive correlation between obesity and arterial stiffness, independent of age. The main finding from this investigation was that among all age groups, an increased BMI was associated with higher levels of cfPWV. Shim et al. (93) corroborate with the aforementioned findings of the correlation between obesity and arterial stiffness. This investigation reported a positive correlation between BMI and cfPWV among a sample of adult women. These findings may be congruent with reduced arterial distensibility and a decreased elastic nature of the aorta that may be due to remodeling of the arterial wall with obesity (18). Moreover, when waist circumference was assessed, the positive correlation between obesity and arterial stiffness was stronger than that of BMI versus cfPWV. These findings are congruent with the current investigation as the relationship between waist circumference and cfPWV ($r = 0.58$, $p<0.001$) may be greater than that of BMI and cfPWV ($r = 0.49$, $p<0.001$). Thus, the distribution of body fatness may be a superior predictor of CVD risk related to increased arterial stiffness than BMI. An increased waist circumference was previously reported as a significant predictor of new onset metabolic syndrome (17, 89) which has been reported to significantly increase arterial stiffness regardless of age (88, 102).

The role of obesity on increased arterial stiffness may also be explained by a number of mechanisms. First, insulin resistance has been linked to increased levels of obesity (8). The effect of hyperinsulinemia on arterial stiffness is not completely understood but might include promotion of vascular smooth muscle cell growth (5), a likely contributor to increased aortic stiffness. Furthermore, high levels of plasma glucose may also contribute to glycation of proteins in the arterial wall (105). Glycation of the arterial wall has been shown to increase arterial stiffness by forming an irreversible link between collagen proteins, which in turn may lead to a reduction in arterial compliance

(120). Additionally, bound insulin has potential vasodilation effects through endothelial derived nitric oxide release (67). Endothelial vasodilation occurs in response to the pressures exerted on the arterial wall. This function is partially accountable for maintaining blood pressure levels and decreased stress to the arterial wall. In the hyperinsulinemic state that may occur with obesity, the effects of bound insulin are reduced preventing the insulin linked endothelial dilation to occur. Therefore, as blood pressure is increased during firefighting activities in an obese firefighter with hyperinsulinemia, accompanying vasodilation may not occur, increasing the possibility for arterial damage and stiffening and decrease thermoregulatory ability. These may be possible mechanisms explaining the elevated arterial stiffness in the over fat, unfit group from the current investigation. However, the current investigation did not include any subjects with known hyperinsulinemia, diabetes or pre-diabetes. Nonetheless, this should not be disregarded as many subjects had not had medical physical examinations in 12 months and may have been unaware of a pre-existing condition.

The association of obesity with increased arterial stiffness may also be explained by increased circulating levels of the hormone leptin (15) and heightened levels of inflammation (112). Increased levels of the hormone leptin have been described to have a similar effect to arterial stiffness as insulin, promoting vascular smooth muscle cell growth (15). It was also suggested that higher levels of inflammatory immune cells in circulation may cause movement of these cells into the arterial wall leading to increased stiffness (112) and have been correlated to an increased cfPWV in an adult population (92). Although these factors may increase arterial stiffness among an obese population, none of these were measured in the current study and can only be speculative explanations for some of the differences in cfPWV between the two groups.

Although CRF did not independently affect arterial stiffness, there was a significant negative correlation between CRF and cfPWV (relative VO_{2peak}: $r = –0.59$, $R^2 = 0.35$ $p < 0.001$; absolute VO_{2peak}: $r = –0.30$, $R^2 = 0.09$, $p = 0.041$), which indicated a moderate inverse relationship between these two measures. This finding is in agreement with Vaitkevicius et al. (106) who reported a significant inverse correlation between CRF and cfPWV ($r = -0.34$, $R^2 = 0.12$, $p < 0.01$) across a large adult age range and a strong significant negative correlation ($r = 0.52$, $R^2 = 0.27$, $p < 0.02$) in older adults (>70 yr). Moreover, Vaitkevicius and coworkers (106) reported that endurance trained athletes between the ages of 54 – 75 years had 26% lower cfPWV measures compared to a sedentary age-matched group with lower CRF levels. This investigation also found no independent effects of BMI on arterial stiffness indicating that those with greater levels of cardiorespiratory fitness may have less arterial stiffening compared to those with lower fitness levels after controlling for BMI.

Corroborating with the findings from the aforementioned investigation, Vlachopoulos et al. (109) reported that an increase in cfPWV of $1.0\ m \cdot s^{-1}$ translated into a 14% increase in risk of experiencing a cardiovascular event and a 15% increase in risk of cardiovascular mortality. These findings suggest that firefighters in the unfit group from the current study whose cfPWV measures were $1.004\ m \cdot s^{-1}$ higher, on average, than the fit group, may be at an elevated risk for a cardiac event. Although some researchers have reported that the largest increases in CVD risk occur when cfPWV measures were above $12\ m \cdot s^{-1}$ (6, 66, 82), Sutton-Tyrell et al. (101) reported that the adult subjects from their investigation with recorded PWV measures of greater than 6.5 $\text{m}\cdot\text{s}^{-1}$ were at a greater risk for CVD than those below this value. These findings are noteworthy as the fit and unfit groups from the current study had average cfPWV of 6.25 $\text{m}\cdot\text{s}^{-1}$ and 7.25 $\text{m}\cdot\text{s}^{-1}$, respectively, suggesting that the unfit group may be at a higher risk for CVD.

Donley et al. (20) investigated the effect of aerobic exercise training on arterial stiffness in adults with the metabolic syndrome. Subjects in this investigation performed 8 weeks of supervised aerobic exercise at 60-85% heart rate reserve, 3 $\text{d}\cdot\text{wk}^{-1}$ for 60 $\text{min}\cdot\text{d}^{-1}$. The primary findings were that after the exercise intervention, subjects with metabolic syndrome decreased cfPWV by nearly 1.0 $\text{m}\cdot\text{s}^{-1}$, indicating a reduced risk for CVD and related CVD events (109). Subjects also increased CRF by nearly 3.0 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, suggesting that the positive alterations in arterial pathophysiology associated with increased fitness could be partially responsible for the reduction in cfPWV.

Reducing CVD risk and increasing CRF through physical activity has been demonstrated among a group of 527 professional firefighters (23). Durand et al. (23) found that increased frequency, duration, and intensity of physical activity, as well as total weekly exercise minutes, were significantly associated with higher levels of CRF. Increased physical activity frequency was also significantly associated with more favorable lipid profiles such as total cholesterol/HDL ratio, triglycerides, and resting plasma glucose. Moreover, increased time spent performing physical activity was significantly correlated with a reduction in cfPWV and suggested that increased exercise duration may attenuate arterial stiffness in older adults (40).

A possible mechanism that may explain the attenuation or reduction of arterial stiffness with increased physical activity may be due to an increase in aortic elastin content (63). Matsuda et al. (63) compared aortic wall elastic components between sedentary and physically active rats. This investigation found that the elastin content in the aorta tissue of the physically active rats was significantly higher than the sedentary controls. The content of aortic collagen was not different between groups suggesting that physical activity does not reduce the rigid component of the arterial wall but increases the elastic nature of the central arteries. This may be due in part to hemodynamic changes experienced during exercise. The stretching or expansion of the aortic wall from increased systolic pressure during exercise may stimulate the synthesis of elastin proteins (19). The increase in aortic elastin content would further enhance the compliance of the aorta and produce a reduction in cfPWV. Although no information was obtained on the physical activity levels of the firefighters in the current study, the positive relationship of physical activity and CRF has been demonstrated in a similar population of firefighters (23). The chronic effect of physical activity on arterial wall structure and its association with increased CRF (23) may explain, in part, the difference in cfPWV seen between groups in the current investigation.

Arterial stiffness is a result of the stress and strain placed on the vascular wall that changes over the lifespan. Reported in many investigations, a strong positive association exists between age and cfPWV (55, 57, 73). Lakatta et al. (55) reported that age associated increases in arterial stiffness may be due to arterial wall thickening, luminal dilation and a reduction in compliance. These alterations are likely due to increased collagen, elastin fractures and reduced elastin, and increased calcification. The decreased compliance of the central arteries may produce an increase in aortic pressure during systole, ultimately leading to increased afterload and an increase in central aortic pressure

(73). A significant positive association between age and cfPWV was also present in the current study. However, there was no difference in age between groups and may not explain the difference seen in cfPWV. Additionally, the average cfPWV values of the fit (6.25 ms^{-1}) and unfit (7.25 ms^{-1}) groups were similar to normal values of those a decade younger and older, respectively (Table 4-6), suggesting that reduced cardiorespiratory fitness and increased relative body fat may account for the increased arterial stiffness.

Table 4-6. Distribution of cfPWV ($m\cdot s^{-1}$) according to the age category in normal values populations (N=1455).

Age (years)	**Mean (±SD) of normal PWV measurements ($m\cdot s^{-1}$)**
<30	6.2 (.75)
30-39	6.5 (1.35)
40-49	7.2 (1.30)
50-59	8.3 (1.90)
60-69	10.3 (2.40)
≥70	10.9 (2.70)

Adapted from Reference Values for Arterial Stiffness' Collaboration, 2010 (82).

A correlation between hypertension and arterial stiffness has also been demonstrated (57). Controlling for hypertension has shown to be beneficial in preventing or delaying the adverse effects of vascular aging (57). Chronically elevated systolic pressure places a high demand on the elastic properties of the ascending aorta. Similar to advanced age, elevated pressure during systole over time can cause elastin fiber damage and fracture (57). These findings may explain why resting brachial and aortic systolic blood pressure among the fit group was significantly less compared to the unfit group. On average, fit and unfit firefighters were considered normotensive and pre-hypertensive at rest, respectively. The chronic effect of increased aortic systolic blood pressure among the unfit group could be a possible mechanism for the elevated cfPWV at rest.

Contrary to these findings, increases in arterial stiffness have been independent of systolic blood pressure (6). Blacher et al. (6) compared measured cfPWV measurements among hypertensive adults with and without atherosclerosis alterations. Atherosclerosis such as arterial wall thickening (74) and calcification and plaque build-up (108) have been associated with increased arterial stiffness. The results from Blacher et al. (6) indicated that the presence of atherosclerosis alterations influenced the increase in cfPWV independent of age and blood pressure. That is, the presence of atherosclerotic plaque in addition to elastic fractures and increased collagen may be responsible for the increased arterial stiffness independent of hypertension.

The unfit group in the current study demonstrated an elevated cfPWV measurement post-exercise compared to the fit group, with no difference in aortic or brachial blood pressures. The findings from Fahs et al. (31) may help explain this finding as post-exercise arterial stiffness may be independent of blood pressure. Fahs et al. (31) studied the effect of firefighting tasks on arterial stiffness in a group of younger (28 ± 1 yr) overweight (mean BMI: 26.9 ± 0.5 $kg \cdot m^{-2}$; range 20.3 – 37.7 $kg \cdot m^{-2}$) firefighters. Arterial stiffness was assessed via cfPWV at rest and approximately 30 minutes following live firefighting activities. There was a non-significant decrease in both brachial and aortic systolic blood pressure approximately 30 minutes post-work accompanied by a significant increase in cfPWV. The researchers suggest that the intermittent high intensity firefighting tasks may be similar to performing heavy resistance exercises and this type of stimulus may have caused the increase in arterial stiffness post-exercise/work similar to that found in earlier investigations (24, 29, 44).

A second investigation may also explain the independent relationship of arterial stiffness and blood pressure. Cote et al. (16) examined post-exercise hypotension in a group of normally active adults (30.5 ± 5.7 yr) following a bout of high intensity interval training. The high intensity interval exercise produced a significant reduction in systolic blood pressure (5.3 mmHg) 30 minutes post-exercise. The measured post-exercise hypotension in the current study may be explained by the decreased diastolic blood pressure likely due to in part the persistent peripheral vasodilation in an attempt to dissipate body heat after completing the exercise protocol (111) in full personal protective equipment. The reported post-exercise hypotension in the investigation by Cote et al. (16) was comparable to the current investigation as the unfit group exhibited a decrease in brachial and aortic systolic pressures 30 minutes post exercise of 8 mmHg and 8.8 mmHg, respectively. The fit group also demonstrated a similar hypotensive response 30 minutes post-exercise. Additionally, brachial and aortic systolic pressures were considered not different between groups at 30 minutes post exercise signifying that both groups experienced a similar hypotensive response due to the exercise stimulus. However, cfPWV remained significantly elevated in the unfit group, demonstrating that cfPWV may be independent of blood pressure in the current study. The elevated cfPWV irrespective of aortic and brachial systolic pressure may be better explained by the aforementioned investigations reporting increased arterial stiffness due to increased obesity (90, 93, 113).

CHAPTER V

SUMMARY & CONCLUSIONS

In summary, the primary purpose of this dissertation was two-fold. The purpose of the first study was to describe and compare the prevalence of cardiovascular disease risk factors and health-related behaviors between volunteer and professional firefighters. The secondary purpose was to compare the prevalence of obesity in firefighters to state and national populations. The results from this study confirmed our first hypothesis that the prevalence of CVD risk factors among volunteer firefighters was greater than professional firefighters. Additionally, these results confirmed our second hypothesis that a majority of firefighters were at moderate-to-high CVD risk and had a greater prevalence for obesity compared to state and national populations.

This is the first study, to our knowledge, that utilized a validated survey to collect data pertaining to CVD risk among volunteer firefighters and assess CVD risk according to ACSM standards. Also, this study differed from other investigations in that we compared our findings to state and national normative data. Furthermore, this study also differs from previous research due to the additional assessment of health-related behaviors associated with CVD risk that may be significant in assessing risk among firefighters.

The purpose of the second study was to evaluate the association of cardiorespiratory fitness and obesity with arterial stiffness in professional firefighters. The results from this study confirmed our hypothesis that the fatter and unfit group had greater resting and post exercise cfPWV measurements than the leaner fit group.

Additionally, a positive association was identified between relative body fat and cfPWV, meaning increased levels of body fat were associated with greater arterial stiffness.

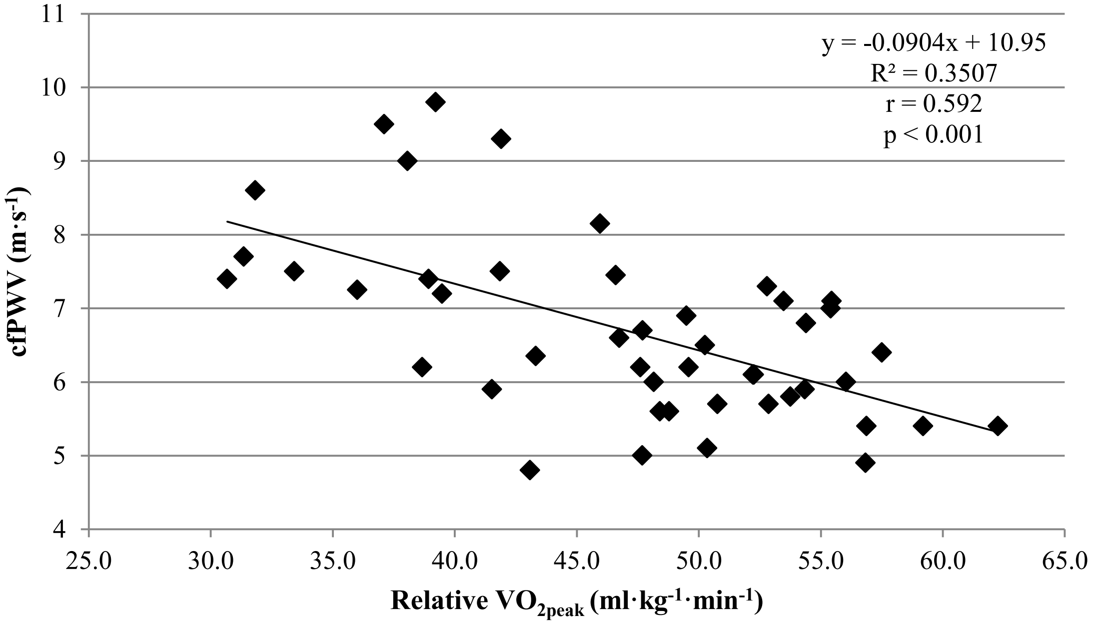
This was the first study, to our knowledge, that assessed the association of cardiorespiratory fitness with arterial stiffness in a group of professional firefighters. A similar study performed by Fahs et al. (31) investigated changes in arterial stiffness post firefighting activities, but failed to assess the association of cardiorespiratory fitness and relative body fatness with arterial stiffness at rest and post-exercise. Although no main effect of fitness grouping was found, a significant difference in cfPWV seen between fitness groups due to the significant difference in relative body fat. Both obesity and cardiorespiratory fitness/physical activity have been associated with arterial alterations that resulted in an increase and decrease to arterial stiffness, respectively.

The use of cfPWV may be an appropriate tool to diagnose CVD risk above and beyond that of traditional CVD risk factors in a firefighter setting. Increased arterial stiffness has been associated with elevated CVD risk independent of hypertension in multiple studies. The results from this investigation support this finding as cfPWV remained elevated in the fatter unfit group when no differences were seen in brachial and aortic blood pressures between groups post-exercise. Also, previous investigations have demonstrated an elevated risk for a sudden cardiac event attributed by an elevated cfPWV independent of traditional CVD risk factors.

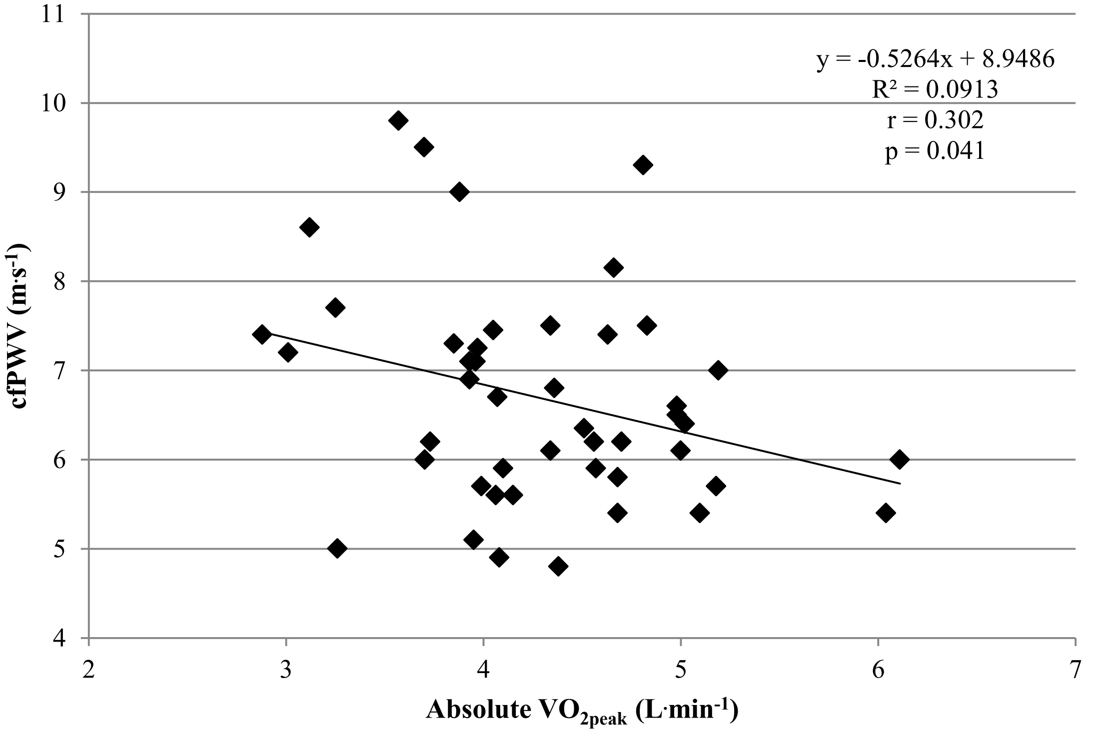
In conclusion, unfit and over-fat firefighters may be at an elevated risk for CVD related events. Firefighters with greater levels of cardiorespiratory fitness demonstrated lesser amounts of arterial stiffness. Also, in accordance with traditional CVD risk factors, a decrease in relative body fat was also associated with less arterial stiffness. The present study highlights the importance of greater cardiorespiratory fitness and body weight management not only for successful completion of fire-related tasks, but for the reduction of CVD risk among an at risk population. Thus, there is a need to evaluate and incorporate dietary and physical activity interventions to reduce the CVD risk of firefighters.

APPENDIX

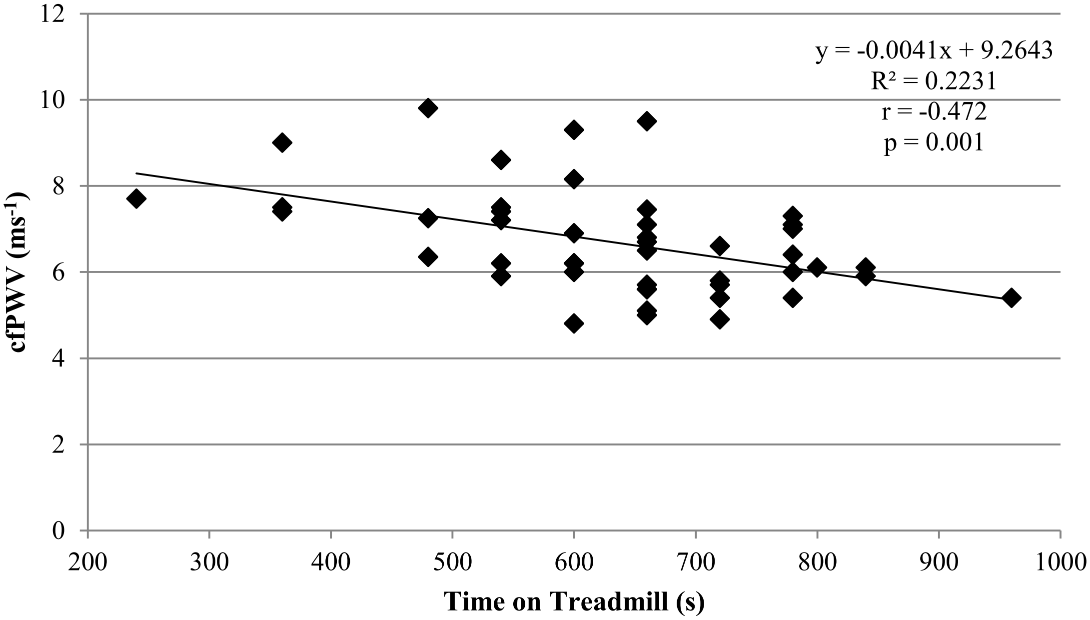
Relationship between relative CRF and cfPWV in 46 Professional Firefighters.



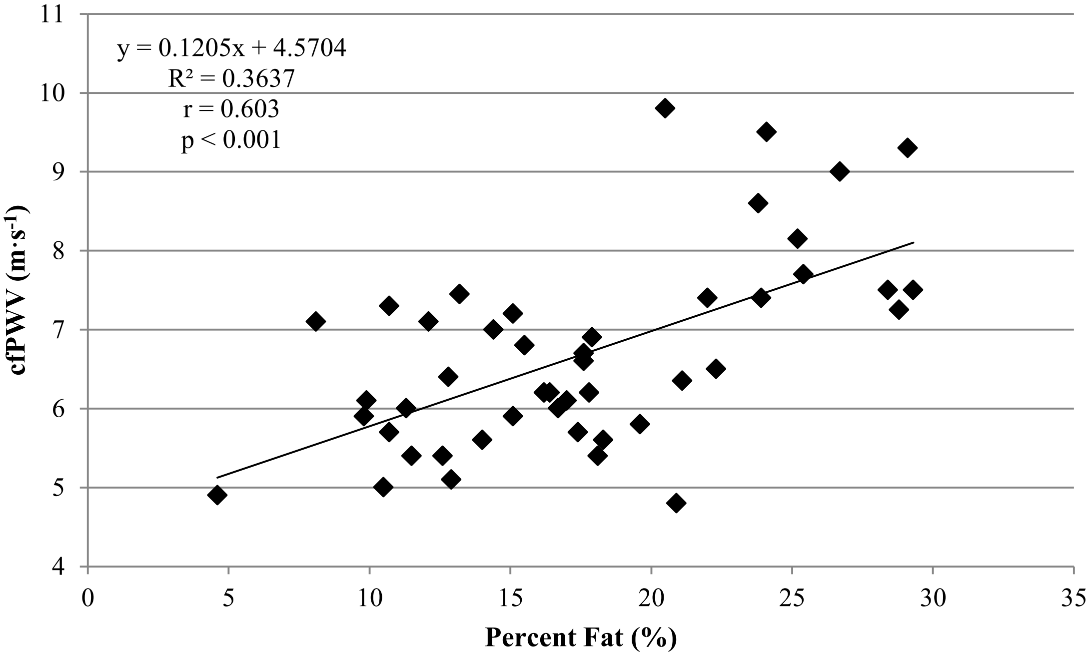
Relationship between absolute CRF and cfPWV in 46 Professional Firefighters.



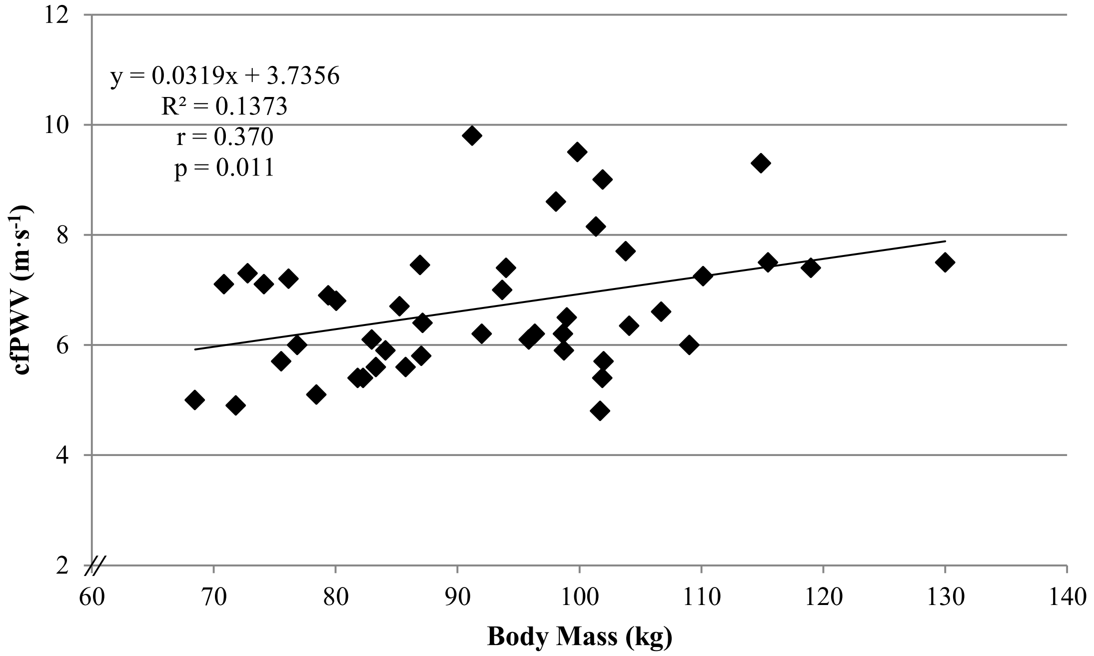
Relationship between Time on Treadmill and cfPWV in 46 Professional Firefighters.



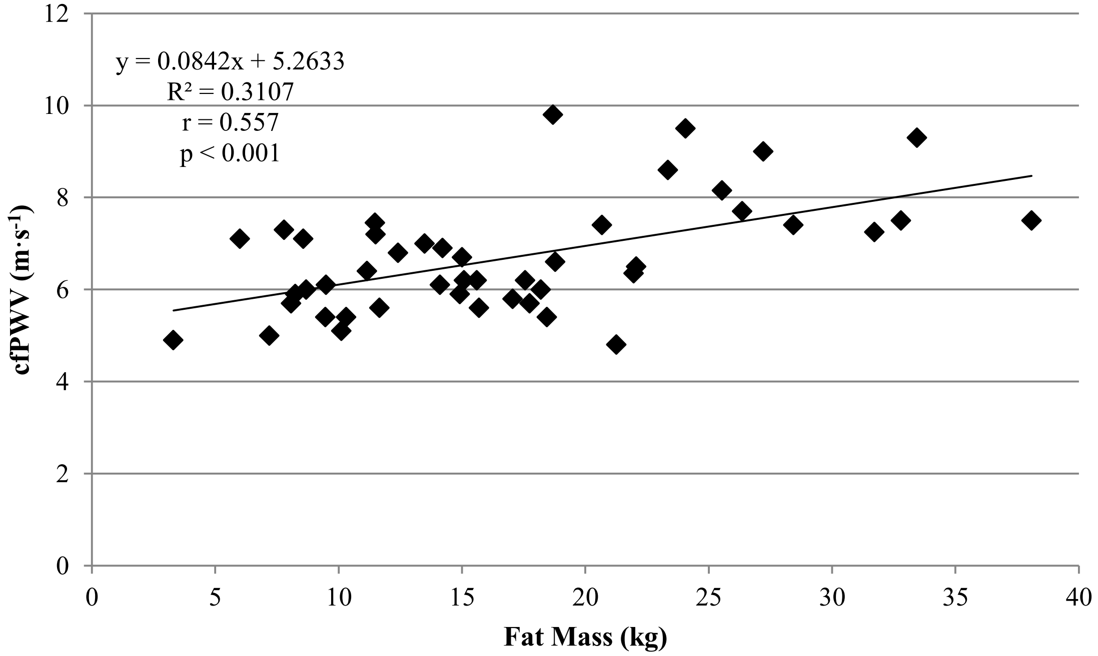
Relationship between Percent Body Fat and cfPWV in 46 Professional Firefighters.



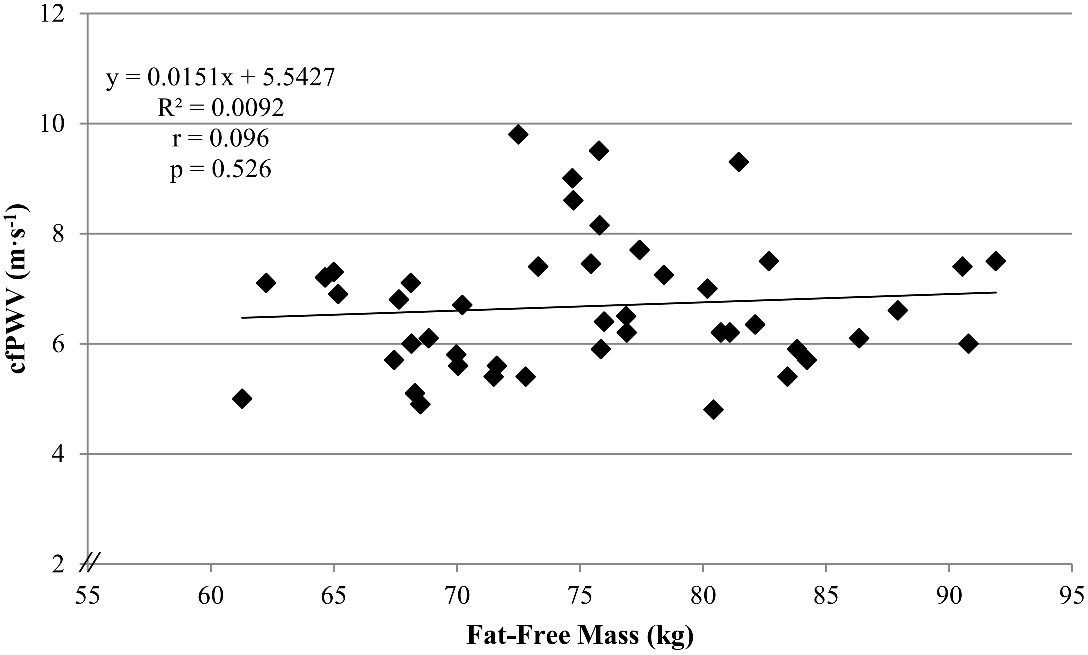
Relationship between Body Mass and cfPWV in 46 Professional Firefighters.



Relationship between Fat Mass and cfPWV in 46 Professional Firefighters.



Relationship between Fat-Free Mass and cfPWV in 46 Professional Firefighters.



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