THE INFLUENCE OF MUSCLE SIZE AND QUALITY ON STAIR-CLIMB PERFORMANCE IN OVERWEIGHT AND OBESE FIREFIGHTERS

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A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirement for the degree of Master of Arts in the Department of Exercise and Sport Science in the College of Arts and Sciences (Exercise Physiology).

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ABSTRACT

CRAIG ROBERT KLEINBERG: The influence of muscle size and quality on stair-climb performance on overweight and obese firefighters. (Under the direction of Bonita Marks)

Climbing stairs has previously been shown to be one of the most relevant firefighter tasks. Furthermore, ultrasound (US) assessments of muscle size and quality have been shown to have significant influence on lower extremity performance. The purpose of this study was to examine the influence of vastus lateralis (VL) size and quality on stair climb performance (SCP). Panoramic US images of the VL were obtained to determine cross-sectional area (CSA) and echo intensity (EI) in 49 overweight and obese firefighters. A timed and weighted SCP assessment was performed upon completion of the US assessment. Our results demonstrated that EI ($r=0.377$, $p=0.008$), but not CSA ($r=-0.031$ $p=0.833$), was related to SCP. When accounting for age and VO$_2$peak, the EI and SCP relationship was attenuated ($r=0.237$, $p=0.108$). Additionally, EI was the only significant predictor of SCP. These findings indicate that lower extremity muscle quality, but not size, may contribute to firefighter SCP.
ACKNOWLEDGEMENTS

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**Figure 1:** Participant leg position during ultrasound acquisition

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Candidate Physical Ability Test (CPAT): a specific, nationally recognized simulated fire rescue test.

Cross-sectional area (CSA): the area of a muscle perpendicular to its fibers observed at the largest point.

Echo intensity (EI): an index of muscle quality obtained through computer-aided grey-scale analysis of the individual pixels within an ultrasound image; representative of the amount of adipose and/or connective tissue in a given cross-sectional scan of skeletal muscle. Values are reported between 0 (all black) and 255 (all white), with greater echogenicity indicating poorer muscle quality.

Echogenic tissue: biological tissue consisting of structural and acoustic differences from that of the more organized tissue thereby reflecting sounds waves back to the surface transducer.

Peak Volume of Oxygen Consumption (VO2peak): peak rate of oxygen consumption that can be utilized in one minute during maximal exercise and measured in ml•kg⁻¹•min⁻¹.

Simulated fire rescue performance: circuit of mock firefighting task to be completed as fast as possible.

Ultrasonography (US): an imaging method using high-frequency sound waves to produce relatively precise images of structures within biological tissue.

Vastus lateralis (VL): the largest of quadriceps femoris muscle group located on the lateral portion of the thigh.
CHAPTER I

Introduction

Firefighters are a critical part of public safety, and firefighting is often recognized as a hazardous profession. There is agreement that firefighters should maintain high levels of physical fitness; however, current research shows a greater prevalence of obesity and lower cardiovascular fitness levels among firefighters than general population counterparts (Poston et al., 2011; Roberts, O’Dea, Boyce, & Mannix, 2002). Poston et al. (2011) reported that over 30% of firefighters were classified as obese per the body mass index (BMI) ≥ 25 kg/m² and met at least one risk factor for metabolic syndrome. Those meeting the standards for metabolic syndrome have 2.5 times increased risk of mortality from cardiovascular disease (CVD; Lakka et al., 2002). Though only accounting for one to five percent of their duties, environmental factors such as sudden heart rate increases, elevated temperature, and dehydration during fire suppression tasks places additional stress on the cardiovascular system increasing risk of sudden cardiac death (SCD) 10-100 fold (Fernhall, Fahs, Horn, Rowland, & Smith, 2012; Kales, Soteriades, Christophi, & Christiani, 2007; Smith, Barr, & Kales, 2013). Furthermore, the self-perception of increased fitness levels may also contribute to the elevated obesity issue among firefighter populations (Peate, Lundergan, & Johnson, 2002).

Not only does general obesity lead to increased risk of CVD, occupational performance of firefighters may be influenced as a result of specific body composition ratios. Michaelides (2011) and associates found a moderate but statistically significant
correlation ($r = 0.57$, $p < 0.01$) between body fat percentage (BF%) and time to complete simulated firefighting tasks. Conversely, two other studies found no relationship between body composition and firefighter performance (Rhea, Alvar, & Gray, 2004; Sheaff et al., 2009). Additionally, Fukumoto et al. (2012) concluded that BF% and BMI did not influence leg extensor strength whereas muscle size and quality of the rectus femoris displayed significant correlations ($r = 0.47$, $p < 0.41$ and $r = -0.40$, $p < 0.01$ respectively) to lower limb strength. Muscle size and quality of the vastus lateralis (VL) has also been associated with cardiovascular and lower extremity functional performance (Cadore et al., 2012; Visser, 2002). Traditionally, magnetic resonance imaging (MRI) and computed tomography (CT) have been consider the gold standard for muscle size and quality analysis; however, advancements in ultrasound (US) imaging technology has made this a safe and reliable alternative to muscle imaging (Rosenberg et al., 2014). Panoramic US imaging allows for concurrent analysis of muscle cross-sectional area (CSA) and echo intensity (EI; Ryan et al., 2014). Reflection of sound waves from echogenic tissue, such as adipose and connective tissue, allows US technicians to obtain real-time images of skeletal muscle architecture (Kremkau, 2002). Increased reflections from adipose and connective tissue are associated with “whiter” images (Pillen et al., 2009). Computer assisted analysis of images allows for quantification of EI values between 0 (all black) and 255 (all white) arbitrary units (Pillen et al., 2006). Use of US technology may provide additional insight into the influence of body composition, or more specifically, muscle size and quality, on firefighter performance.

Often used as a component of firefighter abilities, stair-climb performance is one of the most relevant and demanding tasks among firefighter duties (Michaelides, Parpa,
An average heart rate (HR) of 88% of maximum have been recorded upon completion of the stair-climb, demonstrating high cardiovascular demand (von Heimburg et al., 2006). Stair-climb performance has been assessed through a variety of methods. Commonly used methods include a 3-minute StepMill test at a rate of 60 steps per second, repeated ascension and descension of a set of stairs, or the ascension of a single staircase. All stair-climb performance assessments include the additional weight of either full turnout gear and high rise pack or weighted vest with a weight ranging from 22 - 34 kg (Michaelides, Parpa, Henry, Thompson, & Brown, 2011; Sheaff et al., 2009; von Heimburg et al., 2006). Physiological characteristics influencing stair-climb performance include upper body and abdominal strength, VO$_{2\text{max}}$, and upper body muscular endurance. However, lower body characteristics such as a squat 1-repetition maximum (1RM) and reps to failure have not been associated with firefighter performance (Michaelides et al., 2011; Rhea et al., 2004; Sheaff et al., 2009). Measurements of muscle characteristics such as CSA and EI in vivo may provide researchers with additional information as to the lower body influence of stair-climb performance and overall firefighter ability.

**Purpose**

1. The primary purpose of this study was to examine the influence of vastus lateralis cross-sectional area and echo intensity on stair-climb performance of overweight and obese career firefighters.

2. The secondary aim of this study was to examine the collective contribution of vastus lateralis cross-sectional area and echo intensity on stair-climb performance on overweight and obese career firefighters.
Research Question 1: Does vastus lateralis cross-sectional area influence stair-climb performance in overweight and obese firefighters?

Hypothesis 1: Better stair-climb performance (i.e. quicker times) would be associated with greater vastus lateralis cross-sectional area.

Research Question 2: Does vastus lateralis echo intensity influence stair-climb performance in overweight and obese firefighters?

Hypothesis 2: Better stair-climb performance (i.e. quicker times) would be associated with lower vastus lateralis echo intensity values.

Research Question 3: Does vastus lateralis cross-sectional area and echo intensity collectively predict stair-climb performance in overweight and obese firefighters?

Hypothesis 3: Vastus lateralis cross-sectional area and echo intensity would collectively contribute to the explained variance in stair-climb performance.

Delimitations

1. Participants were between the ages of 18-50 years.

2. Firefighters were rested for 5 minutes in a supine position prior to US measurements. This allowed for fluid shifts and produced more accurate measurements.

3. The depth of the US image remained constant across all participants (4.5 cm).

4. A convenience sample of firefighters from central North Carolina was recruited.

5. The stairwell remained constant across all participants.

6. Participants had adequate vision to perform job duties.

7. Participants had adequate hearing to distinguish verbal cues.
Limitations

1. True random sampling was not used due to accessibility of participant pool.
2. There was no control group due to the nature of a correlational study.
3. Maximal oxygen was predicted using a non-exercise equation.
CHAPTER II

Review of Literature

Introduction

This review of literature will begin with health concerns of firefighters. Factors such as environmental characteristics and obesity and how they influence performance will be discussed. The review will then transition into the use of US assessment of muscle size and quality. The last section of this review will briefly mention physiological influences on simulated firefighting performance. The main focus will be on stair-climb performance and physiological characteristics specifically related to stair-climb performance.

Health Concerns of the Firefighting Profession

Sudden cardiac death. Recent publications from the National Fire Protection Association state that 40% of all on-duty firefighter fatalities were a result of sudden cardiac death (Fahy, Leblanc, & Molis, 2009). This accounted for the greatest portion of fire fatalities for the previous five years. Sudden cardiac death is caused from the high stress environment where it is not uncommon for firefighters to be working from 75-82% of maximal volume of oxygen consumption (VO2max) reaching 90% of their maximal heart rate (HRmax) (Williams-Bell, Villar, Sharratt, & Hughson, 2009). It is recommended that firefighters maintain a measure of cardiac fitness of at least 42 ml•kg⁻¹•min⁻¹ with several studies measuring oxygen consumption over 37 ml•kg⁻¹•min⁻¹ during fire suppression duties (Poplin, Roe, Peate, Harris, & Burgess, 2014; Sheaff et al., 2009; Williams-Bell et al., 2009). Even under these conditions, it is surprising that 40% of deaths occur during fire
suppression duties making up approximately one to five percent of all firefighter duties (Kales et al., 2007). Understanding the cardiovascular strain placed on firefighters may provide valuable insight to the 10-100 fold increased risk of sudden cardiac death among firefighters.

**Environmental contributions for cardiovascular strain.** Contributions to increase risk of firefighter on-duty deaths include near-maximal heart rate (HR) responses, physical work, and environmental stress (Kales et al., 2007). Within 30 seconds of the alarm, HR was shown to increase an average of 47 beats per minute and remained at an average of 30 beats per minute above resting while on the truck en route to an emergency (Barnard & Duncan, 1975). After the initial stress of the alarm reaction, fire suppression duties require large capacity of physical work including hose drag, climbing stair, forced entry, and victim rescue while bearing the additional load of a self contained breathing apparatus (SCBA) weighing up to 25kg (Smith et al., 2013). Williams-Bell and group (2009) found a greater than expected respiratory exchange ratio for the percentage of VO₂ during simulated fire suppression activities suggesting more contribution of anaerobic energy systems.

Increased ambient, core, and skin temperatures lead to increase sweat rates, thereby causing dehydration to become a concern during scenarios that may not allow for adequate fluid consumption. Romet & Frim (1987) documented skin temperatures reaching 37°C during simulated fire suppression tasks. The same study also documented HR and core (rectal) temperature increases corresponding with performance of physical work and environmental conditions. One study (Fernhall et al., 2012) observing cardiac performance during an acute bout of intermittent firefighting training showed a significant increase in core temperature of 1.8°C, a 3.3% decrease in plasma volume, and an overall
decrease in body weight of 1.1%. These physiological responses are similar to those observed during long distance endurance events such as marathons and triathlons. Left ventricular end diastolic volume and stroke volume were found to decrease during over 3 hours of intermittent firefighting bouts without a decrease in pulse pressure. This suggests a decrease in arterial compliance and an overall increase in cardiac work and contributing to sudden cardiac death among firefighters (Fernhall et al., 2012).

**Obesity status among firefighters.** In addition to work environment, the prevalence of obesity among the firefighter population contributes to increased risk of CVD and ultimately sudden cardiac death. In 2005, 44.7% of 2,000 firefighters were found to be obese as defined by a body fat percentage (BF%) greater than 25% and 32% for males and females respectively (Fahy et al., 2009). More recent studies in 2011 and 2012 report the prevalence of obesity to range between 32-42% for volunteer and career firefighters alike (Mayer et al., 2012; Poston et al., 2011). Despite the physically demanding nature of firefighting, the prevalence of overweight and obese firefighters has remained around 75% since 2002 (Clark & Rene, 2002; Mayer et al., 2012; Poston et al., 2011).

Factors such as hypertension, high serum cholesterol, low high density lipoproteins, and hyperglycemia/insulin resistance have all been linked to obesity and are components of metabolic syndrome (Grundy, Brewer, Cleeman, Smith, & Lenfant, 2004). In an 11-year prospective study, Lakka and associates (2002) found that participants meeting requirements for metabolic syndrome nearly tripled their risk of mortality from CVD. In an effort to raise awareness of the metabolic syndrome, the American Heart Association in conjunction with the National Heart, Lung, and Blood Institute established risk factors for metabolic syndrome through the National Cholesterol Education Program. Metabolic
syndrome was defined as an individual having three or more of the following factors: waist circumference >102 cm, blood triglycerides ≥150 mg/dL, high density lipoproteins < 40 mg/dL, blood pressure ≥ 130 ≥ 85 mmHg, and fasting glucose ≥ 110 mg/dL (Grundy et al., 2004). Poston and associates (2011) found that among 478 career firefighters, 33% had a BMI greater than 30 kg/m² and a minimum of 30% of the sample population met at least one risk factor for metabolic syndrome.

**Health concerns for performance.** Not only is the risk of SCD increased by the obesity status of firefighters, job performance is also affected. Despite the demanding nature of the occupation, one study found the average firefighter VO₂max to be 12% less than the average sedentary controls (Roberts et al., 2002). These issues are further complicated by the decreased performance during simulated fire rescue tasks after an acute bout of resistance training (Dennison, Mullineaux, Yates, & Abel, 2012). In Dennison et al.’s study, firefighters performed simulated fire rescue assessment on two separate occasions. Prior to completing the second assessment, firefighters performed two circuits of full body resistance exercises. A 10-minute recovery period was allowed between the exercise session and simulated fire assessment. Nearly a ten percent increase in time to completion and an overall increase in rate of perceived exertion were found after the second assessment. While fatigue was attributed to the decline in performance, their study determined that trained firefighters in a fatigued state outperformed 70% of untrained firefighters at baseline. The authors conclude that on-duty resistance training programs to combat obesity may be efficacious but should be implemented near the end of shifts to prevent fatigue-induced declines in fire suppression tasks (Dennison et al., 2012).
Ultrasound Assessments

The ability to examine skeletal muscle characteristics in vivo is important for evaluation of changes associated with exercise or nutritional interventions and varieties of clinical conditions such as sarcopenia and neuromuscular disorders. Previous authors have used techniques such as magnetic resonance imaging, computed tomography, and US for muscle size and quality (Kent-Braun, Ng, & Young, 2000; Narici, Maganaris, Reeves, & Capodaglio, 2003; Rosenberg et al., 2014). Computed tomography has been considered the gold standard for assessment of muscle size and quality; however use of US to examine muscle size and quality has gained popularity due to its accessibility, portability, and lack of ionizing radiation (Lang et al., 2010; Rosenberg et al., 2014). Originally limited by a narrow field-of-view, advancements in US technology have enabled investigators to utilize expanded field-of-view (panoramic) US techniques. Panoramic brightness-mode (B-mode) US has been shown to be valid and reliable for examining skeletal muscle characteristics (Ryan et al., 2014).

Ultrasound imaging involves the transmission of sound waves through biological tissue and constructs an image from returning sound waves. Biological tissue both transmits and reflects the incident sound, and when viewed in the axial plane, echogenic structures such as the superficial and deep aponeuroses to be viewed (F. Walker, 1996). Adipose and fibrous connective tissue, such as muscle aponeuroses, are echogenic due structural and acoustic differences from that of the more organized muscle (F. O. Walker, Cartwright, Wiesler, & Caress, 2004). The time required for sound to travel through and be reflected by a tissue back to the source may be used to calculate the depth of the reflector (Kremkau, 2002). As the depth of penetration increases, there is a need for amplification of
more distant echoes. This amplification is referred to as time-gain compensation, or simply “gain” (Kremkau, 2002). The time difference of reflected sound waves from echogenic structures to the transducer allows researchers to obtain real-time ultrasound imaging of skeletal muscle architecture and CSA estimations.

Panoramic US imaging may provide simultaneous assessment of muscle CSA and quality. During US, structural differences have been linked to increased amounts of fat and/or connective tissue resulting in increased US beam reflections and a corresponding “whiter” image (Pillen et al. 2009; Ryan et al. 2014). Echo intensity has previously been graded visually on Heckmatt's scale, which primarily relied upon a comparison of EI reflected from the muscle with that of the bone. This was a 4-point graded scale where grade I represented normal muscle and grade IV represented very strong muscle echo and complete loss of bone reflection (Heckmatt, Leeman, & Dubowitz, 1982). This method does have limitations however. Assuming the reflection of an acoustic US wave is most direct when the propagation direction of the wave is perpendicular to muscle fibers, EI may be influenced by the angulation of fascicles (Madaras, Perez, & Sobel, 1988; Narici et al., 2003). Additionally, this method is dependent on the experience of the observer and may be subject to considerable inter-observer interpretations (Pillen et al., 2006).

Recently, sonographic evaluations have utilized computer-assisted quantitative grey-scale analysis of individual pixels of a selected region of interest to determine EI on a scale of 0 (all black) to 255 (all white) arbitrary units (Rosenberg et al., 2014). Objective evaluations of quantitative data from computer-assisted EI analysis is more sensitive than visual scoring and may be more suitable for statistical analysis because greater echogenicity (a value closer to 255) indicates poorer muscle quality (Pillen et al., 2006).
Accordingly, computerized grey-scale evaluation of EI may be more applicable for research purposes.

**Firefighter Performance**

Occupational duties of firefighters consist of many physically demanding tasks such as pulling or dragging hoses, carry victims to safety, and forced entry, all while carrying the additional weight of personal protective equipment (Dennison et al., 2012; Michaelides et al., 2011; Sheaff et al., 2009). These tasks elicit significant stress on cardiorespiratory function as demonstrated by heart rates of 88% of age-predicted max during actual emergencies (Sothmann, Saupe, Jasenof, & Blaney, 1992). Cardiovascular and muscular demands of simulated fire rescue tests show similar stress through heart rates reaching greater than 90% of maximal heart rate and blood lactate levels greater than 13 mmol/L (von Heimburg et al., 2006; Williams-Bell et al., 2009).

**Simulated fire rescue demands.** A common firefighting simulation test is the Candidate Physical Ability Test (WFI, 2007). During this test, candidates progress through a predetermined sequence of events that best simulates their use at the scene of a fire while wearing a 22.68 kg vest to simulate the weight of the self-contained breathing apparatus and other protective clothing. This evaluation consists of stair-climb performance, hose drag, equipment carry, ladder raise, forcible entry, search simulation, dummy drag, and ceiling breach and pull (Sheaff et al., 2009; Williams-Bell et al., 2009). Candidates must walk between events and may be disqualified upon a second running infraction. Performance is graded in a pass/fail fashion with a maximal total time of 10 minutes and
20 seconds (WFI, 2007). Resulting from stringent requirements, the CPAT has become nationally recognized firefighting assessment.

Several fitness variables have been associated with performance on the CPAT. It has well been documented that firefighting tasks require relative maximal oxygen uptake greater than 40 ml•kg⁻¹•min⁻¹ (Sothmann et al., 1992; von Heimburg et al., 2006; Williams-Bell et al., 2009). Significant negative correlations between performance time and 1 repetition max (1RM) bench press (r = -0.66, p ≤ 0.05), sit-ups to failure (r = -0.41, p < 0.1), and power assessed through the Wingate anaerobic cycling test (r = -0.66, p < 0.01; Rhea et al., 2004; Sheaff et al., 2009; Williams-Bell et al., 2009). Additionally, differences in performance have been associated with differences in age, upper body strength, peak power, and VO₂max (Michaelides et al., 2011; Sheaff et al., 2009; von Heimburg et al., 2006). These studies indicate successful firefighting performance requires contributions of both aerobic and anaerobic fitness. Firefighters not meeting minimal fitness requirements may not be prepared to perform the required duties of the profession.

**Stair-climb performance.** Romet & Frim (1987) determined one of the most demanding firefighter activities to be building search and rescue. It was reported that there were greater increases in heart rate by firefighters spending the most time in search and rescue tasks. Another study assessing physiological responses of firefighters during simulated rescue found that the average time to ascend 6 floors was 90 (±31s) seconds, and during that time, average heart rate achieved was 88% (±4%) of maximal measured heart rate during VO₂max test (von Heimburg et al., 2006). In another study (Michaelides et al., 2008), after completion of one simulated firefighting test, participants rated the relevance of each the tasks to a firefighter’s job. On a five-point scale where a score of 1 meant “not relevant”
at all and a score of 5 indicated “very relevant,” the average score of the 38 participants was a 4.63 (±0.49). Because of its perceived relevance and demanding nature, stair-climb performance is included in the CPAT and considered a valid and reliable method for evaluation of job-specific performance among firefighters (Dennison et al., 2012; Plat, Frings-Dresen, & Sluiter, 2010; von Heimburg et al., 2006).

Stair-climb performance has been evaluated through several methods. According to the Wellness Fitness Initiative CPAT 2nd edition manual, a warm-up is performed on a Stairmaster StepMill for 20s at a rate of 50 steps per minute. The test begins at the end of the 20s at a rate of 60 steps per minute for 3 minutes while wearing a 22.68 kg weight vest plus an additional 11.34 kg simulating the weight of a high rise pack (hose bundle; WFI, 2007).

Michaelides and associates (2008, 2011) conducted stair-climb assessments consisting of the ascension and descent of 12 steps eight times (96 total) while wearing a 22.68 kg weighted vest. One study, using a stair-climb performance assessment consisting of ascending and descending 13 stairs five times (65 total), established a high reliability with an intraclass correlation coefficient of ICC = 0.937 for simulated firefighting test (Dennison et al., 2012). Using a stair-climb performance assessment consisting of a 20m climb (108, 110, or 117 steps) carrying a high rise pack in turnout gear, Plat and associates (2010) found a high reliability of the stair-climb performance assessment one week and three weeks after baseline with an ICC of 0.82 and 0.91 respectively.

**Influences on stair-climb performance.** Several physical attributes have been linked to stair-climb performance. In 2004, overall fitness, including cardiovascular endurance, anaerobic endurance, muscular endurance and strength has shown a moderate negative
correlation ($r = -0.51, p \leq 0.05$) to overall stair-climb time (Rhea et al., 2004). As with CPAT, attributes such as power ($r = -0.39, p < 0.01$), maximal repetitions of push-ups ($r = -0.39, p < 0.01$), and sit-ups to failure ($r = -0.50, p < 0.01$) have also been associated with stair-climb performance (Michaelides et al., 2011; Sheaff et al., 2009). Interestingly, lower body measures such as squat repetitions to failure and one repetition maximal strength measures (1RM) have not shown any significant correlation to stair-climb performance (Michaelides et al., 2011; Sheaff et al., 2009). Therefore, a focused effort on improving these fitness parameters could improve performance on related firefighting tasks.

There is disagreement to the degree of contribution of body composition to firefighter performance. Michaelides et al. (2008) reported a significant correlation ($r = 0.41, p < 0.01$) between BF% and simulated firefighter rescue time. In a follow-up study, BF% was found to be significantly correlated ($r = 0.56, p < 0.01$) with stair-climb performance and the strongest predictor of a firefighters time to completion on simulated fire rescue (Michaelides et al., 2011). Conversely, two studies showed no significance between body composition firefighter performance (Rhea et al., 2004; Sheaff et al., 2009). More direct measurements of muscle quality may provide insight into lower extremity performance among firefighters. For instance, Fukumoto and associates (2012) found that BF% and BMI did not significantly influence muscle strength, whereas muscle thickness and EI of the rectus femoris displayed significant associations ($r = 0.47, p < 0.41$ and $r = -0.40, p < 0.01$, respectively) with lower limb strength. Additionally, lower muscle CSA and greater fat and connective tissue infiltration of the mid-thigh musculature was associated with decreased performance on lower extremity functional performance such as
a 6m-walk test and a sit-to-stand (five repetitions with arms folded across the chest) test (Visser, 2002). Using a Cox’s proportional hazard regression analyses, Visser and colleagues (2005) reported men and women in the lowest quartile of muscle CSA to be 2.25 and 1.70 times more likely to develop mobility limitations over the 3-year follow-up period. Additionally, participants with the greatest amount of fat infiltration of the mid-thigh muscle were 50% -80% more likely to develop mobility limitations, independent of CSA (Visser et al., 2005). Significant negative relationships have also been found between rectus femoris EI and workloads at the first (r = -0.43, p = 0.01) and second (r = -0.50, p = 0.01) ventilatory thresholds (Cadore et al., 2012). Collectively, these studies suggest a potential influence of mid-thigh muscle size and quality on firefighter performance; however to our knowledge, no study has examined the direct relationship between leg extensor CSA and EI on firefighter stair-climb performance.

**Conclusion**

Though fire suppression tasks only consist of small portion of total firefighter responsibilities, sudden cardiac death during these tasks remains the number one cause of on-duty deaths. The physical nature of the occupation warrants a high level of fitness; however there are conflicting findings on the influence of body composition on firefighter performance. Therefore, assessment of muscle size and quality *in vivo* may provide new insights regarding the influence of body composition on firefighter performance.
CHAPTER III

Methodology

This study was a prospective cross-sectional design utilizing data collected for Dr. Eric D. Ryan’s larger approved study entitled “The effect of a meal replacement shake on energy intake, body composition, blood lipids, skeletal muscle characteristics simulated performance, and quality of life in overweight and obese firefighters” (UNC-IRB # 14-1045). All participants read and signed consent forms, which were approved by the University of North Carolina’s Office of Human Research Ethics Institutional Review Board prior to completing any testing.

Participants

Forty-nine healthy but overweight and obese career firefighters (aged 18-50 years) were recruited from local fire departments within a 30-mile radius of The University of North Carolina at Chapel Hill. All participants provided standard medical clearance for the occupation prior to participation. Participants were excluded if they had a neuromuscular, cardiopulmonary, and/or metabolic disease. Participants were also excluded for any of the following reasons:

1. Pregnancy or intent to become pregnant,
2. Current or past history (3 mo.) of joint or muscle problems of the lower body that would not allow them to complete the testing,
3. The participant's physician did not provide consent for exercise, and/or
4. Echo cardiogram abnormalities were found suggesting cardiovascular disease.
Additional exclusionary criteria included:

1. Participants who performed heavy resistance training (one hour for at least 3 days a week) within the past 3 months,
2. Sport nutrition products supplementation (e.g. creatine, whey protein, beta-alanine, etc.) within the last 3 months, and/or
3. A 15 pounds weight change within the last month.

Experimental Design

Participants visited the laboratory on two separate occasions, separated by 3-10 days. The first visit consisted of a familiarization trial, followed by an experimental session. During the familiarization visit, participants completed a health history questionnaire, exercise status questionnaire and a written informed consent document approved by the University’s Institutional Review Board. The participants then practiced a weighted stair-climb performance assessment by ascending and descending the designated stairwell with the weighted vest one time, to ensure they are comfortable with all procedures.

Prior to the experimental session, participants refrained from vigorous physical activity for 24 hours and arrived to the laboratory following an eight-hour fast (except for water). During the experimental session, stature and body mass (BM) were assessed. Percent body fat (BF%) was determined using the four-compartment model as described below. Following body composition, a panoramic US image of the vastus lateralis (VL) was acquired to examine muscle size and quality. Upon completion of the US assessments, participants were provided a light snack and were permitted time for digestion prior to the timed weighted stair-climb assessment.
Instrumentation

Height was measured using 0.1 cm using a calibrated stadiometer (Detecto, Webb City, MO, USA), and weight was measured to the nearest 0.1 kg on a scale (Model BWB-627-A, Tanita Inc., Arlington Heights, IL, USA). Dual-energy X-ray absorptiometry (DEXA) was used to measure bone mineral content (BMC, Hologic Discovery W, Bedford, MA, USA). Body volume (BV) was assessed using a calibrated BOD POD® (COSMED, Inc., Concord, CA, USA). Bioimpedance spectroscopy (BIS) was used to measure total body water (TBW, ImpediMed SFB7, ImpediMed, Inc., Carlsbad, CA, USA). Muscle CSA and EI of the VL was assessed using an US imaging device (LOGIQ E5, General Electric Company, Milwaukee, WI, USA) and a multi-frequency linear-array probe (12L-RS: 5-13 MHz: 38.4 mm FOV) with the panoramic function (LogicView, General Electric Company, Milwaukee, WI, USA). Image-J software (version 1.46r, National Institutes of Health, USA) was used to determine muscle CSA and EI for all ultrasound images. Limb length was measured in centimeters using a plastic Gulick tape measure (AliMed, Dedham, MA, USA).

The light snack consisted of a commercially available meal replacement shake (Appendix A. GNC Total Lean™, General Nutrition Centers, Inc., Pittsburgh, PA, USA). Participants wore a 22.73 kg-weighted vest (Z Fitness Inc., San Jose, CA, USA) during the stair climb assessment. Stair-climb performance will be assessed by time to completion (seconds) using a handheld digital stopwatch (Robic SC-505W, Marshall-Browning Int’l Corp, Oxford, CT, USA). BMI was used to determine overweight and obesity status (overweight BMI ≥25; obese BMI ≥30) using the equation BMI = weight (kg)/height (m²).
Cardiorespiratory fitness (VO₂peak) was estimated using a physical activity questionnaire developed by Jackson et al. (1990) and printed in Ross and Jackson (1990).

**Procedure**

**Body composition.** A four-component model for body composition was used to determine fat mass, fat-free mass and BF% using air displacement plethysmography DEXA, and BIS as described by Wang et al. (2002). The formula to determine fat mass (FM) was:

\[
FM = 2.748(BV) - 0.600(TBW) + 1.129(BMC) - 2.051(BM)
\]

where BV was body volume (L), TBW was total body water (kg), BMC was bone mineral content (kg), and BM was body mass (kg). Body fat percentage was then calculated using the equation:

\[
BF\% = \frac{FM}{BM} \times 100
\]

Air displacement plethysmography was used to measure BV using the Bod Pod®, which determines BV based on the inverse relationship between air volume and pressure under isothermal conditions and represented by Boyles Law \((P_1/P_2 = V_2/V_1)\). Prior to testing, the Bod Pod® was calibrated using a two-point calibration according to manufacturer’s instructions. First it was calibrated with an empty chamber, and then with a known 50L cylinder. Before testing, participants removed all metal, including jewelry, watches, necklaces, and glasses. Body mass was then measured to the nearest 0.1 kg on the system’s calibrated electronic scale with the participants wearing tight fitting spandex and a swim cap. Female participants were also required to wear a sports bra. Participants were then instructed to sit as still as possible in an upright position and to breathe normally during the BV measurements. A minimum of two trials were performed. If the
difference between the first and second measurement was greater than 3 ml/L \(^*\) (mean volume in L), a third measurement was performed. Thoracic gas volume was predicted and has previously been shown to be similar to measured volumes, even among obese populations (Demerath et al., 2002; McCrory, Molé, Gomez, Dewey, & Bernauer, 1998).

Total body water (TBW) was estimated using BIS following manufacturer’s instructions. The BIS works by sending a current through the body and measuring the resistance of impedance (Ω) to that current. Bioelectrical impedance spectroscopy has been shown to produce valid estimations of TBW when compared to criterion methods using deuterium oxide (Matthie et al., 1998; Moon et al., 2007). Following five minutes of rest, measurements were taken while the subject was lying in a supine position on a non-conductive surface with arms and legs not touching. Excess hair was shaved and the site was cleaned with alcohol and gauze to remove any interference. Two electrodes were placed 5 cm apart on the right hand and wrist. The first electrode was placed superior to the wrist, medial to the ulnar head. The second was placed proximal to the third metacarpophalangeal joint, 5 cm from the first electrode. Two electrodes were placed 5 cm apart on the right foot and ankle with the first electrode placed superior to the ankle between the lateral and medial malleoli. The second electrode was placed 5 cm below the first, proximal to the second metatarsophalangeal joint.

Dual-energy X-ray absorptiometry was used to estimate total body bone mineral content. Bone mineral content was then converted to bone mineral (Mo) using the following equation as described by Wang et al. (2002): \( Mo = \frac{\text{total body bone mineral content}}{0.9582} \). Prior to all assessments, the DEXA was calibrated according to
manufacturer guidelines. After removing all metal objects from their person, participants laid supine in the middle of the scanner bed with their arms to their sides.

**Ultrasonography.** Prior to US assessments, participants rested for 10 minutes in a supine position to allow for fluid shifts (Berg, Tedner, & Tesch, 1993). All US imaging was performed on the right limb at 50% of the distance between the greater trochanter and the femoral condyle. Participants were lying in a supine position on a padded table with the knee propped at 30 degrees of flexion (Figure 1).

**Figure 1:** Participant leg position during ultrasound acquisition.

Cross-sectional area assessments of the VL was performed in the musculoskeletal mode with equipment settings, including gain (68 dB), depth (4.5 cm), and frequency (10 MHz), optimized for image quality in musculoskeletal mode and held constant across participants. A custom made probe support composed of high-density foam padding was positioned perpendicular to the longitudinal axis of the muscle and fastened with an adjustable Velcro strap to ensure US probe movement in the transverse plane. The probe was then moved from the most lateral aspect of VL to the medial boarder in a slow
continuous movement. In order to prevent possible near field artifacts, water-soluble hypoallergenic transmission gel was applied to enhance acoustic coupling (Rosenberg et al., 2014).

**Image analysis.** All US images were analyzed using Image-J software. Prior to each analysis, images were individually scaled from pixels to centimeters using the straight-line function. The straight-line function allows users to draw a straight line from two points. After scaling the images, subcutaneous fat was determined using the straight-line function to measure the distance from the skin to the superficial aponeurosis. The selected region of interest included as much muscle as possible without the surrounding fascia. The polygon function was used to determine CSA. Using the same region of interest, EI was assessed by computer-aided gray-scale analysis using the standard histogram function. The mean EI value were reported as the corresponding index of muscle quality ranging between 0 and 255 arbitrary units (a.u.; black = 0; white = 255) (Rosenberg et al., 2014). Values of EI were then corrected for subcutaneous fat as outlined by Young and associates (Young, Jenkins, Zhao, & McCully, 2015).

**Stair-climb assessment.** Prior to the start of the test, participants performed a warm-up by ascending and descending 26 stairs (height: 20cm) once (i.e. one round trip) without the weighted vest. Immediately after completing the warm up, the 22.73 kg vest was placed over the participants’ shoulders. A verbal command (“3-2-1-go”) was provided to signal the start of the test. Beginning at the bottom of the staircase, participants ascended and descended the stairs four times (104 total steps) as fast as possible without stopping or holding on to the handrails. All participants were required to ascend and descend each step one at a time with one foot touching each step (Plat et al., 2010). Time began with the
verbal cue to prevent random delays and stopped when participants reached the last stair with both feet. Research assistants provided strong verbal encouragement and announced the completion of each full lap. Upon completion of the stair climb assessment, the weight vest was removed.

**Estimated Cardiorespiratory fitness.** Aerobic fitness (VO₂peak) was calculated using a non-exercise prediction equation. Using the Physical Activity Scale (PAS;\(^{1}\)) described by Ross and Jackson et al. (1990), participants rated their average weekly physical activity participation. The activity history contained in the medical history form was also used to assist in determining the correct rating. After obtaining the physical activity rating, estimated aerobic fitness was determined using the following equation (Jackson et al., 1990):

\[
VO₂peak = 50.513 + 1.589 \times PAS – 0.289 \times age – 0.552 \times BF\% + 5.863 \times gender.
\]

Gender was dummy coded with coefficients of “0” and “1” for females and males, respectively. This equation was developed and validated at the Cooper Aerobics Clinic (Dallas, TX) in a subject population of 2,801 men and women ranging from 21-82 years of age. The resultant non-exercise VO₂ peak multiple regression equation using BMI demonstrated good association to the measured VO₂ peak obtained from the max testing (multiple correlation R = 0.794; p < .01, SE = 5.55 mL/kg/min). It was reported that this non-exercise VO₂ peak prediction model was appropriate for 96% of the adult population (Jackson et al. 1990; Ross and Jackson 1990).

**Statistical Analysis**

Power calculations were determined with G*Power software (Version 3.1.9 Dusseldorf, Germany) using the procedure discussed by Beck (Beck, 2013). Based on
previous EI effect sizes, a statistical power (1-\(\beta\)) of 0.8 with two predictors requires an estimated sample size of 30 to produce a moderate effect size (\(F^2=0.38\)). Therefore, a sample size of 40 was recruited to account for potential participant attrition (Fukumoto et al., 2012). Normally distributed descriptive data is presented as means (± standard deviations). A Pearson product moment correlation was used to determine the relationship between stair climb performance, CSA, EI, and \(\text{VO}_2\text{peak}\), respectively. Additionally, two partial correlation coefficients were used to determine the relationship between stair climb performance and CSA accounting for age and estimated cardiorespiratory fitness, and the relationship between stair climb performance and EI accounting for age and estimated cardiorespiratory fitness.

A stepwise multiple regression analysis was used to determine the contributions of CSA and EI to stair-climb performance. All statistical procedures were performed using the SPSS statistical package, Version 20 (IBM; Chicago, IL). An alpha level of \(p \leq 0.05\) was used to determine statistical significance for all data analyses. Multicolinearity was identified via the variance inflation factor as calculated by the SPSS program. The accuracy of the model (i.e. cross validation) was calculated using Stein’s adjusted \(R^2\) equation to evaluate the amount of shrinkage.

In summary the above statistical analysis was applied to the following research questions and corresponding hypothesis:
Research Question 1: Does vastus lateralis cross-sectional area influence stair-climb performance in overweight and obese firefighters?

**Hypothesis 1:** Better stair-climb performance (shorter times) would be associated with greater vastus lateralis cross-sectional area.

Research Question 2: Does vastus lateralis echo intensity influence stair-climb performance in overweight and obese firefighters?

**Hypothesis 2:** Better stair-climb performance (shorter times) would be associated with lower vastus lateralis echo intensity values.

Research Question 3: Does vastus lateralis cross-sectional area and echo intensity collectively predict stair-climb performance in overweight and obese firefighters?

**Hypothesis 3:** Vastus lateralis cross-sectional area and echo intensity would collectively contribute to the explained variance in stair-climb performance.
CHAPTER IV

Results

Participant Characteristics

Forty-nine firefighters (47 males, 2 females) were recruited from central North Carolina fire departments participated in this study. Physical characteristics, ultrasound measurements, and stair-climb time are presented in Table 1. The Shapiro-Wilk test for normality indicated VO$_{2\text{peak}}$, and time were not normally distributed ($p = 0.049$; and $p = 0.38$ respectively). Therefore, the natural log for the aforementioned variables were used for further analyses.

Relationship between CSA, EI, and Stair-Climb Performance

The Pearson product moment correlation demonstrated that CSA and age were not significantly associated with stair-climb time ($r = -0.031, p = 0.833; r = 0.107, p = 0.464$). However, EI demonstrated a significant relationship with stair-climb time ($r = 0.377, p = 0.008$) and VO$_{2\text{peak}}$ ($r = -0.602, p < 0.001$). When controlling for age and VO$_{2\text{peak}}$ combined, there remained no significant relationship between CSA or EI and stair-climb time (respectively, $r = 0.105, p = 0.483; r = -0.237, p = 0.108$).
Table 1: Participant Characteristics

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>36.5 ± 7.3</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>36.8 ± 7.28</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>29 ± 5.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.5 ± 7.3</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>180.1 ± 6.9</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>167.0 ± 7.2</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>106.7 ± 20.0</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>107.7 ± 19.6</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>83.2 ± 15.4</td>
</tr>
<tr>
<td>BF%</td>
<td>30.8 ± 5.5</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>36.6 ± 3.4</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>30.5 ± 5.5</td>
</tr>
<tr>
<td>VO\textsubscript{2peak}</td>
<td>35.8 ± 6.3</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>31.5 ± 3.5</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>36.0 ± 6.3</td>
</tr>
<tr>
<td>Stair-Climb Time (sec)</td>
<td>86.3 ± 14.6</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>86.3 ± 14.6</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>99.0 ± 15.6</td>
</tr>
<tr>
<td>CSA (cm\textsuperscript{2})</td>
<td>38.9 ± 8.0</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>39.4 ± 7.8</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>28.3 ± 3.1</td>
</tr>
<tr>
<td>EI\textsubscript{corrected} (a.u)</td>
<td>103.6 ± 15.9</td>
</tr>
<tr>
<td>Females (n = 2)</td>
<td>102.4 ± 15.1</td>
</tr>
<tr>
<td>Males (n = 47)</td>
<td>131.6 ± 6.3</td>
</tr>
</tbody>
</table>

The stepwise regression analysis suggested EI, but not CSA, was a significant predictor of stair-climb time and 14% of the variance can be explained by EI (Table 2).

Because it was not significantly related to stair-climb time, age was not accounted for in the regression analysis. Stein's $R^2$ equation resulted in shrinkage of 0.046 for the predictive model. Multicollinearity did not exist because EI did not exceed 1 / (1 – $R^2$) = 1.17.

Table 2: Stepwise Regression Analysis

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Constant</th>
<th>beta</th>
<th>t value</th>
<th>p value</th>
<th>Variance Inflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>VL, EI</td>
<td>4.049</td>
<td>0.377</td>
<td>2.794</td>
<td>0.008</td>
<td>1.00</td>
</tr>
</tbody>
</table>
CHAPTER V

Discussion

A number of previous studies have examined the relationship among various physiological variables and simulated stair-climb tasks in firefighter personnel (Michaelides et al., 2011; Sheaff et al., 2009; Williams-Bell et al., 2009). However, no published literature was found that examined the influence of lower extremity muscle size and quality on firefighter performance. Recent technological advances in ultrasonography allow for the simultaneous assessment of muscle size (CSA) and quality (EI) from a single panoramic image (Rosenberg et al., 2014). The primary findings of the present study indicated that EI, a measure of muscle quality, but not CSA, was significantly related to stair-climb performance in overweight and obese firefighters. However, when accounting for age and cardiorespiratory fitness ($\text{VO}_{2\text{peak}}$), this relationship was attenuated. In addition, muscle quality was the only significant predictor of stair-climb performance. These results contribute to the current knowledge of factors influencing the performance of occupational duties among firefighters.

Relationship Between EI and Stair-Climb Performance

The present study showed a significant relationship between EI and stair-climb performance (e.g. poorer muscle quality associated with slower stair-climb time). In agreement with our findings, several studies have suggested that EI may influence lower extremity performance (Fukumoto et al., 2012; Visser et al., 2005; Wilhelm et al., 2014).
For example, Fukumoto et al. (2012) demonstrated an inverse relationship between muscle quality assessed through EI and isometric strength of the quadriceps in middle aged and elderly adults. Additionally, several studies observed significant inverse relationships between EI and lower extremity functional performance (Cadore et al., 2012; Visser et al., 2005). For example, poorer muscle quality doubled the risk for mobility limitations in elderly men and women when performing tasks such as climbing stairs (Visser et al., 2005). Furthermore, EI has demonstrated a significant inverse relationship ($r = -0.50, p < 0.01$) with submaximal workloads during a graded cycle ergometer test (Cadore et al., 2012). Together, these results suggest that decreases in muscle quality may impair the ability of firefighters to perform physically demanding occupational duties. As previously stated, controlling for age and VO$_{2\text{peak}}$ collectively resulted in negating the relationship between EI and stair-climb time. This may be attributed to the strength of the relationship between VO$_{2\text{peak}}$ and stair-climb time ($r = -0.602, p < 0.001$).

Greater EI values have been reported to be a result of increased US beam reflections and have been linked to increased amounts of intramuscular fat and/or connective tissue (Pillen et al., 2009; Reimers et al., 1993). Reimers et al. (1993) examined the relationship between EI and interstitial fibrous tissue and fat. Echogenicity was compared to total triglyceride content of the corresponding biopsy of 83 muscle samples ($n = 83$). The authors concluded that intramuscular fat, rather than fibrous tissue constitutes the primary cause for increased EI (Reimers et al., 1993). More recently, Pillen and associates (2009) reported significant correlations between EI and the amount of fibrous tissue ($r = 0.87, p < 0.01$) in canines with muscular dystrophy. Furthermore, this relationship remained after correcting for fat content ($r = 0.88, p < 0.001$). The authors concluded that
increased EI was caused by infiltration of both fat and fibrous tissue, however the relative contributions of fat and fibrous tissue to mean EI may not be determined from EI values alone (Pillen et al., 2009). Collectively, these results suggest that increases in intramuscular fat and/or connective tissue may contribute to greater muscle echogenicity.

**Relationship Between CSA and Stair-Climb Performance**

Previous studies have shown significant correlations between skeletal muscle CSA and lower extremity performance (Fukumoto et al., 2012; Visser, 2002). Fukumoto and associates (2012) reported an age-related decrease in muscle size (muscle thickness) contributed to reduced strength of the quadriceps femoris \( r = 0.32, p < 0.01 \). In 2002, Visser et al. (2002) concluded that elderly men and women with lower muscle CSA had poorer performance in lower extremity functions such as a sit-to-stand test and 6 meter walk test. A follow-up study in 2005 determined that persons in the lowest quartile of muscle CSA had twice the risk for mobility limitations during everyday functions such as climbing stairs (Visser et al., 2005).

Contrary to those studies, the results of the present study indicated a non-significant relationship between CSA and stair-climb performance, even when accounting for age and cardiorespiratory fitness. This suggests that muscle size may not influence lower extremity functional assessments. The current study’s results are in agreement with a study performed by Cadore and associates (2012), which concluded that muscle size did not influence submaximal or maximal cardiovascular performance variables in elderly men during an incremental cycle ergometer test. Cadore et al. (2012) suggested neural factors
such as muscular recruitment and firing rate having greater influence rather than size, however this is beyond the scope of the present study.

One potential explanation for the findings of the present study may be related to the body mass and composition of the sample population. Participants recruited for this study were categorized by BMI as overweight or obese. A study performed by Janssen and associates (2000) indicated a significant relationship ($p < 0.001$) between skeletal muscle size and body mass in men and women ($r = 0.69$ and $r = 0.65$, respectively). These authors concluded that heavier persons required greater muscle mass for movement. Future studies may wish to normalize measures of muscle size with body size. Additionally, all previous studies discussed above have examined the relationship between CSA and lower extremity performance in an older population (51 - 87 years; Fukumoto et al., 2012; Visser, 2002; Visser et al., 2005). In the present study, the mean age for our population was in the mid-thirties (range: 24 – 50 years). It may be possible that CSA may not be a significant contributor because this population did not have the age related changes in size (sarcopenia) that is often seen in older adults as a result of loss of physical function and/or disability (Fukumoto et al., 2012; Visser, 2002). Therefore, it is possible that in younger populations that have not experienced these changes in CSA, increases in muscle size may not be sufficient to compensate for greater BM during lower extremity performance assessments.

**Limitations and Future Research**

There are some limitations with this study that must be acknowledged. First, the sample population was a relatively homogenous sample of men and women from central
North Carolina and may not be representative of the true population. Additionally, due to the low female study sample (n = 2), future investigations should make a concerted effort in the recruitment of female firefighters. Furthermore, VO$_{2peak}$ was estimated using a predictive equation. It is possible that the measurement of true cardiorespiratory fitness may alter the relationship of both variables, EI and CSA, to stair-climb performance. Lastly, muscle quality was estimated using EI using grey-scale analysis, echogenicity of the tissue may be altered due to the hypoechoic nature of large areas of fat cells such as subcutaneous fat (Reimers et al., 1993). Future investigations may wish to examine the influence of muscle size and quality normalized to body mass on stair-climb performance across a more heterogeneous population.

**Conclusion**

Occupational duties of firefighters consist of many physically demanding tasks. Climbing stairs has previously been shown to be one of the most demanding and critical firefighter tasks. Additionally, ultrasound (US) assessments of muscle size and quality have been shown to have a significant influence on lower extremity performance. The results of the present investigation suggest that decreased muscle quality was associated with poorer stair-climb performance in overweight and obese firefighters; however muscle size was not related to stair-climb performance. When accounting for age and VO$_{2peak}$ combined, muscle size demonstrated a similar, non-significant, relationship with stair-climb performance. Increased echogenicity resulting from intramuscular fat and connective tissue may contribute to decreased performance in physically demanding occupational tasks such as climbing stairs during actual emergencies. Results of the present study indicate that muscle quality may be a significant predictor of stair-climb performance.
In conclusion, training programs designed to improve occupational performance among firefighters should focus on improving muscle quality. Additionally, more research is needed involving female firefighters to ascertain if their responses and needs are similar to their male counterparts.

Based on the present study, the following research questions and hypotheses were addressed:

Research Question 1: Does vastus lateralis cross-sectional area influence stair-climb performance in overweight and obese firefighters?

Hypothesis 1: Better stair-climb performance (shorter times) would be associated with greater vastus lateralis cross-sectional area.

This hypothesis was rejected because the Pearson product moment correlation indicated a non-significant relationship between cross-sectional area and stair-climb time.

Research Question 2: Does vastus lateralis echo intensity influence stair-climb performance in overweight and obese firefighters?

Hypothesis 2: Better stair-climb performance (shorter times) would be associated with lower vastus lateralis echo intensity values.

This hypothesis was accepted because Pearson product moment correlation indicated a significant relationship between echo intensity and stair-climb time.
Research Question 3: Does vastus lateralis cross-sectional area and echo intensity collectively predict stair-climb performance in overweight and obese firefighters?

**Hypothesis 3:** Vastus lateralis cross-sectional area and echo intensity would collectively contribute to the explained variance in stair-climb performance.

_This hypothesis was rejected because the stepwise multiple regression indicated echo intensity as the only significant predictor for stair-climb time._
# APPENDIX 1: GNC TOTAL LEAN® NUTRITION FACTS

**Nutrition Facts**

<table>
<thead>
<tr>
<th>Amount Per Serving</th>
<th>% Daily Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories</td>
<td>170</td>
</tr>
<tr>
<td>Calories from Fat</td>
<td>50</td>
</tr>
<tr>
<td>Total Fat</td>
<td>8g</td>
</tr>
<tr>
<td>Saturated Fat</td>
<td>1.5g</td>
</tr>
<tr>
<td>Trans Fat</td>
<td>0g</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>20mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>39mg</td>
</tr>
<tr>
<td>Potassium</td>
<td>475mg</td>
</tr>
<tr>
<td>Total Carbohydrate</td>
<td>8g</td>
</tr>
<tr>
<td>Dietary Fiber</td>
<td>3g</td>
</tr>
<tr>
<td>Protein</td>
<td>25g</td>
</tr>
</tbody>
</table>

**Amount Per Serving**

- **Riboavin**: 23%
- **Niacin**: 23%
- **Vitamin B-6**: 23%
- **Folic Acid**: 23%
- **Vitamin B-12**: 23%
- **Biotin**: 23%
- **Pantothenic Acid**: 23%
- **Phosphorus**: 6%
- **Iodine**: 25%
- **Magnesium**: 25%
- **Zinc**: 25%
- **Selenium**: 25%
- **Copper**: 25%
- **Manganese**: 25%
- **Chromium**: 25%
- **Molybdenum**: 25%

**Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.**

- **Calories**: 2,000, 2,500
- **Total Fat**: Less than 65g, 78g
- **Sat. Fat**: Less than 20g, 25g
- **Cholesterol**: Less than 300mg, 375mg
- **Sodium**: Less than 2,400mg, 2,400mg
- **Potassium**: 3,500mg, 3,500mg
- **Total Carbohydrate**: 300g, 375g
- **Dietary Fiber**: 25g, 30g
- **Total Sugars**: 23g, 28g
- **Protein**: 50g, 60g

**Ingrdients:*** Filtered Water, Dried Skim Milk, Proprietary Protein Blend (Milk Protein Concentrate, Whey Protein Concentrate, Calcium Caseinate), and Less than 2% of: Sunflower, Soybean and/or Canola Oil, Cocoa Processed with Nibs, Maltodextrin, Vitamin & Mineral Blend (Potassium Citrate, Magnesium Phosphate, Sodium Phosphate, Potassium Phosphate, Sodium Ascorbate, Ferric Orthophosphate, Zinc Amino Acid, Tocopheryl Acetate, Biotin, Vitamin A Palmitate, Niacinamide, Phytomenadione, Potassium Iodide, d-Calcium Pantothenate, Chromium Chloride, Copper Amino Acid, Cyanocobalamin, Sodium Molybdate, Sodium Selenite, Folacin, Cholecalciferol, Pyridoxine Hydrochloride, Riboflavin, Thiamine, Manganese Sulfate), Lactase, Natural and Artificial Flavors, Cellulose Gum, Acesulfame Potassium, Dextrose, Sucrose, Caramel Color, Salt.

**Contains:** Milk.

Suitable for individuals following a low lactose diet.

**Notice:** Use in conjunction with the Total Lean meal and exercise plan found on gnc.com.

Store in a cool, dry place.

For more information:
1-888-462-2548

**GNC Guarantee**

Use any GNC supplement for as long as 10 days. If you are not 100% completely satisfied, return the unused portion of the product with proof of purchase to your GNC store for a complete refund of your purchase price. No questions asked!
REFERENCES


