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Effect of Musculoskeletal Training on Risk of Occupationally-Related Injuries in Firefighters

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Effect of Musculoskeletal Training on Risk of Occupationally-Related Injuries in Firefighters

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Abstract

Effect of Musculoskeletal Training on Risk of Occupationally-Related Injuries in Firefighters

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In 2011, the U.S. Bureau of Labor Statistics documented injury rates of musculoskeletal injuries requiring days away from work in the full-time firefighter work force at approximately 185/10,000 employees. **This represents a staggering cost to municipalities in overtime salaries as well as departmental readiness to meet community needs.**

We propose, in year one of the project, to observationally determine the prospective association between physical performance measures at baseline and risk of future musculoskeletal injury in a cohort of municipal firefighters of the Austin Fire Department (AFD). We will implement an injury registry surveillance system as well as utilize the AFD Wellness Center physical fitness evaluation of all firefighters within AFD. The prospective association between changes in physical performance measures and risk of musculoskeletal injury within a cohort of AFD firefighters will allow determination of risk of occupational injury incidence and injury severity.

To study the effect of musculoskeletal training on lowering the risk of occupationally-related injury, we will conduct a randomized cluster cross-over trial. The critical intervention will be a strength training intervention of six months duration, implemented in Year 2. There are a total of 43 fire stations in the AFD. We will randomize 50% of the fire stations in a strength training intervention for six months with the remaining 50% of fire station participating for the second six months. Changes in fitness, strength, and incidence of injury will be monitored for the 12 months of this design. Results from this study will be disseminated to firefighting agencies with strategies for occupationally-related musculoskeletal injury prevention.

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A. Narrative

A.1 Background

Firefighting is a physically-demanding job that requires a physical and mental readiness for response to many types of situations. Job tasks during firefighter responses vary, but most include carrying and installing hoses, climbing ladders, search and rescue, and using tools and machinery to make way through doors, walls, debris, etc. To be able to successfully meet job tasks, firefighting requires a basic level of physical fitness and readiness. Components of physical fitness are generally defined as aerobic capacity, muscle strength and endurance, coordination and agility. Most municipal fire departments require minimal standards of physical fitness for successful hiring of new recruits. Further, incumbents may require specialized job training for using advanced techniques and equipment. Physical fitness is a key aspect of this successful job training and several reports and papers have addressed physiologic demands of tasks related to firefighting [1-3].

Firefighting is one of the most dangerous occupations. According to the National Fire Protection Association (NFPA), 69,400 injuries to firefighters occurred in the line of duty in 2012 and an estimated 14,350 injuries to firefighters (20.6%) resulted in lost work time [4]. Considering the denominators, the US Bureau of Labor Statistics (BLS) estimated a total of 235,400 people employed in fire protection jobs in the US in 2011 and an annual injury incidence rate of 13.5% of full-time workers [5]. Of those 13.5/100, 8.6/100 (64%) could be classified as serious, since they resulted in days away from work, job transfer, or restricted duty.

Although information is available on the physiologic demands of firefighting tasks and the rates of job-related injury among firefighters, relatively little is known regarding the role that physical fitness and physical training plays as a possible strategy to reduce the occupational musculoskeletal injury burden among firefighters. Indeed, the majority of injuries (57.0%) related to firefighter duties in 2012 (fire and non-fire related) were related to a musculoskeletal diagnosis (strains, sprains, dislocations and fractures) [4]. Risk factors for musculoskeletal injury, and the role of physical training to reduce the risk of musculoskeletal injury, has been most thoroughly studied in military recruits [6].

Clearly, these statistics present an opportunity to assess the role that physical fitness plays in the risk of injury among firefighters and to translate these findings into prevention practices that may be incorporated for minimizing these risks. The overall goal of this project is therefore to study the role of physical fitness and physical training in the prevention and reduction of job related musculoskeletal injuries among firefighters. We intend to build on our experience with a fitness training program for firefighters to determine its utility in helping to prevent musculoskeletal injuries among full-time employed firefighters in a municipal fire department.

A.2 Specific Aims

The proposed project has four specific aims. During the course of this project we will:

1) Determine the prospective association between physical performance measures at baseline and risk of future musculoskeletal injury in a cohort of municipal firefighters. a) We will implement an injury registry and surveillance system designed to document incident cases of occupationally-related injuries and observationally relate the results of an annual physical fitness evaluation to the risk and severity of occupational injury in these firefighters. We hypothesize that firefighters with higher levels of physical fitness (aerobic power, muscular strength and endurance) will have a lower risk of occupational injury than peers with lower levels of physical fitness, and any injuries that do occur will be less severe.
2) Determine the prospective association between changes in physical performance measures and risk of musculoskeletal injury in a cohort of municipal firefighters. a) We (Co-I Bill Kohl and his post-doctoral fellow) will assess annual changes in physical fitness components and relate these changes over time to the risk of occupational injury incidence and injury severity. We hypothesize that firefighters

who improve or maintain physical fitness will have lower risk of occupational injury than peers who do not improve and the severity of those injuries will be lower than similar, less fit peers.

3) Develop, implement and evaluate a physical training program to lower the risk of musculoskeletal injury.
   a) Using a previously pilot tested strength training program as a basis, we (Roger Farrar, PI, and his post-doctoral fellow), will test the efficacy of fire station-based physical training in these firefighters to improve muscle strength and endurance. This program will be implemented by Roger Farrar and his Graduate Research Assistant, to assure that all firefighter are provided with standardized strength training
   b) We will test the ability of this program to reduce the risk of occupational injuries in these firefighters. We hypothesize that firefighters in the training program will improve muscle strength and endurance and lower risk of occupational injury than peers who do not participate in the program.
4) Determine the return-on-investment (ROI) of the strength training intervention program.
   a) We (Bill Kohl and his post-doctoral fellow) will estimate the averted medical care costs and productivity costs (absenteeism) due to the intervention as they related to the cost of intervention. We hypothesize a positive return - meaning the costs of averted absenteeism and averted injuries related to the intervention exceed the costs of the intervention. The economic impact and statistical assessment of these interventions will be carried out by Dr. Bill Kohl and his post-doctoral fellow.

B. <u>Research Strategy</u>

B.1 Significance

The job of a firefighter requires high levels of physiological demands on the body. Job tasks include unique activities like pushing, pulling, dragging, hauling and climbing. The presence of these various physical tasks suggests that a high level of physical fitness is also required to carry out these demands. If fitness is less than desirable, early fatigue to physiological systems, increased incidence (or risk) of injury, loss of time on duty, or an increase in light duty assignment, may occur. Any of these consequences will ultimately lead to a decrease in ability to sufficiently perform job tasks.

Physical fitness encompasses a wide range of characteristics, including aerobic capacity, anaerobic capacity, muscular strength and endurance, flexibility, and body composition. Aerobic capacity is most popularly measured in terms of the maximum oxygen consumption while anaerobic capacity is usually indirectly measured in terms of a 400m sprint-run time. Muscular strength is defined by multiple means, including maximum force production using free weights, and/or a dynamometer, while muscular endurance is measured by the time that a specific force can be applied. Flexibility is defined as the range of motion of specific joints and is most commonly measured in lower back and upper legs through a sit-and-reach test for distance. Body composition is measured by various means, but is simply defined as the amount of lean mass to fat mass in the body. Though there are multiple measures of fitness, the characteristics that most closely align with the specific job demands of firefighting are upper and lower body muscular strength, upper and lower body muscular endurance, and anaerobic endurance with some, but less significance, on aerobic endurance [7-8]. Pilot work conducted at the University of Texas demonstrates that enhanced muscle mass correlates with a greater passing rate for candidates tested in the Candidate Physical Ability Test (CPAT) qualifying test, and an enhanced muscle mass correlates with greater power [9-11]. These parameters have high correlation with the anaerobic nature of firefighting. This suggests that training for fitness should be specific to the specific physiological characteristics that experience the most stress during job performance.

B.1.1 Fitness Standards in Firefighters

The acceptance of the importance of physical fitness factors for performing firefighter tasks has led to a wide variety of methods within fire departments to assess physical readiness of both applicants and incumbents. While the NFPA (standard 1583) [12] recommends yearly fitness assessments covering the fitness areas of aerobic capacity, body composition, muscular strength, muscular endurance, and flexibility to include optional testing methods, there is not a consistency of measurement at a national level. Likewise, many departments provide job task simulation test instead of a fitness test battery such as the CPAT or Combat Challenge.

The application of any type of physical performance standard has to meet several legal requirements, but the basic issue is that of a test and test standard being "job related". That is – the tests and standards must predict the ability to perform the essential functions (tasks) of the job. Because of this, fire departments (to have legally defensible standards) have viewed applicant or incumbent standards in terms of job capabilities, NOT injury prevention. That has been a major reason for the application of job task simulation tests/standards. Since physical fitness factors can be shown to be the underlying physical abilities to perform job tasks, we are of the opinion that fitness tests and standards are the better alternative because they can accomplish BOTH goals of ensuring job performance capabilities, and reduction and prevention of injuries and health risk.

B.1.2 Effects of Training

Increases in physical fitness result from consistent physical training regimens. These observations have been in the literature for years, particularly in relation to athletic performance. As has been documented and employed in a multitude of athletic performance outcomes, specificity of training is critical for optimizing athletic or job-related performance. The CPAT draws heavily on job-related tasks as criteria for potential employment on the firefighting force and, as demonstrated in our laboratory, field-based tests in either CPAT or Combat Challenge tests rely on power as the critical aspect for job performance outcomes. Recent studies have focused on firefighters specifically. It has been observed that firefighters who undergo a training program consisting of cardiovascular training, resistance training, training for job-specific activities, and stretching, experienced significant improvements in aerobic capacity, muscular endurance, flexibility, and muscular strength [13]. Similar improvements (aerobic capacity, muscular strength and body composition) were seen in Army cadets following basic training [14]. In a 2012 study comparing trained (two, one-hour exercise sessions per week consisting of circuit training and aerobic exercises for approximately one year) versus untrained firefighters, those who were trained completed a simulated fire ground test faster than 81% of their untrained counterparts [15]. In addition, when introduced to a health promotion intervention program meant to enhance ideal fitness behaviors, a group of firefighters experienced slight improvements in body composition, aerobic fitness, and eating habits after a year follow-up but were not maintained long-term [16]. These studies show that improvements in physical fitness measures occur through consistent and specific training programs.

The training program designed by our laboratory, in cooperation with the Austin (Texas) Fire Department (AFD), demonstrated a dramatic increase in passing rates across 5 classes of women volunteers. Prior to our training program in 2000, passing rates were 5-15%. After participating in our training program, passing rates rose substantially to 65-100%. As outlined below, a key component of this training was increase in strength – 15% in upper body and 31% in lower body. There is a well-established correlation between an increase in muscle mass of a person and an increase in power in this individual [9-11]. Force-velocity curves have demonstrated that while the maximum velocity of shortening of a muscle group does not increase, the velocity of the muscle group shortening against a specific load (power) does increase. The years of training that athletes undergo in sports with a premium in power have documented this repeatedly [9]. We have demonstrated in our laboratory, utilizing magnetic resonance imaging (MRI) serial sections, that muscle mass is highly correlated to power, both in a power test on a bicycle ergometer [11] or on a similar power test on a rowing ergometer [10].

B.1.3 Musculoskeletal Injuries Risk

Presumably, decreasing injury risk in firefighters should result in an improvement in job performance. With the majority of firefighter injuries being musculoskeletal in nature, the most inherent correlates of those injuries would appear to be muscular and flexibility fitness factors. Previous research [17-19] suggests that both muscular strength and muscular endurance, especially in the body core and back, are the underlying factors that enable a firefighter to perform the many strenuous tasks of the job. As a consequence, public safety agencies have implemented physical fitness programs, with an emphasis on strength conditioning, as a preventive measure to reduce the risk for job-related musculoskeletal injuries. Short-term assessments [5, 20-22] have shown, at a general level, that such programs do increase musculoskeletal fitness among firefighters and may (cross-sectionally) be associated with general injury prevention. A recent study randomly selected 11 fire departments in the central United States and had their fire fighters fill out a survey about various health and exercise habits and work-related injuries. Those who reported that they engaged in regular on-duty exercise were approximately half as likely to sustain a non-exercise related work injury [23]. However, there are few, if any, longitudinal data to provide a prospective assessment of physical fitness and risk of injury in firefighters or the types of injury that may be associated with fitness training.

Most of the research on fitness and injury risk (including firefighters, police officers and military professionals) have identified risk factors for musculoskeletal injury during training of recruits and trainees, while not as much interest has been placed on workers who are already in the workforce. For example, Jones et al. [24] observed an increase in risk of musculoskeletal injury in Army infantry trainees with age, low levels of previous activity, low frequency of running before training, low physical fitness before training, high running mileage during training, and with high and low levels of flexibility. Also, in a group of Army soldiers undergoing basic combat training, those with lower maximal oxygen consumption, fewer maximal number of push-ups and sit-ups (2-minute test), slower 3.2 kilometer run time, and those who smoked pre-training, were associated with increased injury risk [25]. In addition, poor lower body strength has also been associated with increased risk of stress fractures, a specific type of musculoskeletal injury, in military recruits during basic training [26]. In terms of job-related injuries, participation in competitive sports (i.e. basketball, volleyball) during on-duty fitness activities resulted in a greater increase in incidence of musculoskeletal injury than any other type of physical activity [27]. These findings suggest that a carefully designed fitness program, which avoids potentially risky activities (high running mileage and competitive sports) and promotes improvements in muscular strength and endurance, could result in less incidence of injury in recruits and incumbent firefighters. In a recent review of evidence-based priorities for evidence-based prevention of musculoskeletal injuries, Jones et al [6] call for more data from intervention trials to advance our understanding of effective prevention strategies in the military. The similarities between job demands and lack of data among firefighters make this an important parallel lesson.

An associated issue is the relationship of aerobic power to firefighter fatal injuries. *On average, 40% of firefighter deaths are caused by sudden cardiac death, with an estimated 46% of those precipitated by overexertion. Seventy-eight percent of those cardiac deaths from overexertion were due to myocardial infarction and 18% were from strokes.* With the relationship between higher levels of aerobic fitness and lower cardiovascular risk factors and cardiac events being well documented [28], the value of aerobic training as part of agency fitness/wellness programs is also established to prevent fatal injuries.

The role of fitness programs as part of an injury prevention strategy for firefighters is noted by the National Fire Protection Association (NFPA). The NFPA provides recommendations for all United States Fire Department to establish fitness and wellness programs with specific recommendations for aerobic, muscular strength and endurance, and flexibility training requirements [12]. This problem is exacerbated by the fact that 73% of fire departments are volunteer fire departments [29]. This places the burden of physical fitness and strength training on the individual. To date, there has not been a recommendation of the NFPA with regard to strength training of incumbent firefighters as a preventative measure to reduce incident of injury.

From a health and injury prevention perspective, strength, muscular endurance, aerobic power, and flexibility are consistently accepted as important factors for an agency to address in a fitness/wellness program. One additional consideration is the “job relatedness” of any fitness area. In order for a fire department to have mandatory fitness programs or applicant and incumbent fitness standards, those fitness areas, tests and standards must demonstrate *legally* that they are job-related. This has caused much litigation over the years. The “core” test for demonstrating job-relatedness is that the agency must have validation data to support predictive validity of a fitness area, test or standard for a firefighter’s ability to perform the essential functions of the job at a minimally effective level. Past validation studies with public safety agencies [22, 30, 31] have consistently shown that not only are muscular strength, muscular endurance, aerobic power, and flexibility valid, but also anaerobic power, explosive power and agility are valid. Consequently, a comprehensive fitness/wellness program should also address those areas. In essence, a fitness/wellness program designed as an injury prevention program should also be a job-related training program to facilitate firefighters “physical readiness’ to perform critical job functions/tasks.

B.1.4 Costs

The economic cost of firefighter injuries, fatalities and prevention is difficult to establish. The U.S. Commerce Department has attempted to estimate such costs [32]. The difficulty in determining the economic cost is because future medical costs and injuries typically often occur at a time more distant than the study. In combining direct costs (medical costs) as well as indirect (labor related costs such as lost wages, overtime wages, disability, retirement etc.), the US Commerce Department estimates a total cost of $3,219 per injury, with an estimated lifetime injury cost of $18,231 per firefighter (using the value of the dollar in 2005). As with cost estimates of smoking and vehicle accidents, such estimates, while not solid "true" figures, still provide a meaningful expenditure for injuries to a department. The Commerce Department study also attempted to provide cost estimates for firefighter training to prevent injuries. The estimates, however, take into account firefighter gear, equipment and non-fitness/wellness training. As such, they do not provide a meaningful estimate for prevention efforts aimed at just fitness/wellness factors. The report does note that the mean cost for a department fitness/wellness program is approximately $50,000. Unfortunately, these national survey statistics do not provide the necessary detailed nor longitudinal data to draw any realistic conclusions about cost savings from injury prevention programs aimed at fitness development as a strategy.

A recent report [33] highlighted some economic issues related to musculoskeletal disorders and injury among firefighters. Changes in treatment guidelines, worker's compensation changes, imposition of caps on medical care visits, and reimbursement for treatment and physical therapy are current concerns. Musculoskeletal injuries can result in short-term and long-term disabilities and can have a substantial impact on fire departments when cumulative days off work are considered. Coupled with return-to-work decisions and standards, a strong argument can be made that understanding ways to reduce the risk of occupationally-related musculoskeletal injuries among firefighters could lead to cost savings.

B.2 Innovation

This proposal is innovative in a variety of ways:

1) First, we seek to develop prospective data on the role that physical fitness may play in occupational injury prevention among firefighters. Most of the work in physical fitness has centered on job task analysis, fitness standards for performance, and job readiness. We know of no longitudinal data relating physical fitness parameters to the risk of occupationally-related injuries in firefighters.

2) Second, injury data in municipal fire departments are rarely found in a centralized system nor has a standardized definition for injury severity been consistently used. Most often, these data are relegated to the employee's medical record only. Our work will focus on developing a registry and surveillance system for occupationally-related injuries among firefighters using consistent nomenclature.

3) Third, we seek to translate these findings and test a fitness intervention program designed to prevent occupational injuries among firefighters by increasing and/or maintaining physical fitness.

4) Fourth, the study leverages an ongoing partnership between the University of Texas and the Austin Fire Department (AFD). This unique relationship has been in place for nearly 10 years and will be able to achieve more than if either the AFD or the University was to attempt such a project independently.

B.3 Approach

B.3.1 Preliminary Studies

Our group brings substantial expertise to the current proposal in the form of training and preliminary studies. This experience includes work in the AFD, follow-up studies, and longitudinal studies of musculoskeletal injury, fitness assessment and standards development in public safety agencies and strength training intervention work.

B.3.1.1 Analyses in Austin Fire Department (AFD)

As part of our ongoing relationship with the AFD, we have been evaluating the data collected with each annual fitness evaluation for firefighters in the AFD. Working with Jill Craig and Paul Parrish of the AFD Wellness Department, we have collected, organized and analyzed fitness assessment data from tests that are conducted annually on all AFD firefighters. These fitness assessments, conducted with a routine medical screening, include an estimation of maximal oxygen uptake (maximal or submaximal treadmill testing) and field tests of upper body strength and power, lower body power, body composition, and lower back and hamstring flexibility. The table below illustrates a small part of this rich data source (means and standard deviations).

Variable	2007			2008			2009			2010		
	n	mean	sd	n	mean	sd	n	mean	sd	n	mean	sd
Aerobic Capacity (ml/kg/min)	970	51.4	10.0	913	42.7	6.1	852	43.1	6.2	891	43.3	5.7
Body Mass Index (kg/m^2)	1094	28.2	3.7	1033	28.3	3.8	842	28.4	3.7	952	28.3	3.8
Systolic Blood Pressure (mg/dl)	1139	121.9	29.2	1057	120.8	13.0	893	116.8	13.1	967	115.4	12.7
Endurance Push-up (number)	1065	36.9	13.6	1006	35.6	13.0	836	37.3	13.8	933	36.4	13.7

Table 1. 2007-2010 Fitness Testing Data from AFD Firefighters.

These fitness data are available from 1999 to the present, and assessments are conducted each year. Moreover, given the long-term employment of many members of the AFD, several hundred firefighters have fitness data over multiple years. For example, 661 firefighters have up to 10 years of fitness observations, 1,001 have five or more years of fitness data and 1,260 have at least two years of data. These early analyses indicate that we have the ability to work well with AFD to analyze and organize their fitness data. Further, they show that there is a substantial wealth of information available to correlate these fitness data (and change in fitness) to risk of musculoskeletal injury.

B.3.1.2 Follow-up Studies

Our group has substantial experience in developing prospective follow-up studies. Dr. Kohl has a longstanding interest and experience in the conduct of prospective studies. For many years, Dr. Kohl was the Co-investigator of the Aerobics Center Longitudinal

Study, which has followed patients of a preventive medicine center for morbidity and mortality outcomes over a 30-year period. This study, with many publications over the past 25 years, was one of the first to document the independent predictive ability of physical fitness, and improvements in fitness, for risk of all-cause and coronary heart disease mortality [28, 34]. The techniques and skills to successfully follow this cohort will be extremely valuable in helping to achieve the Specific Aims of the present proposal.

Dr. Kohl also has valuable previous experience in conducting randomized physical activity trials. Specifically, he was a Co-investigator for Project Active, a 24-month NIH-funded physical activity behavioral intervention trial designed to test the effectiveness of a lifestyle intervention in improving and maintaining physical fitness [35-37]. Sedentary men and women were randomized into either a structured or lifestyle physical activity intervention for 6 months, and then both groups were followed for an addition 18 months. Significant and comparable improvements in physical activity (energy expenditure) and physical fitness (maximal oxygen uptake) were seen in both groups, as were changes in other cardiovascular disease risk factors. This study showed that a behavior lifestyle of physical activity intervention was as effective in improving health as a traditional, structured (gym-based) approach.

B.3.1.3 Fitness Assessment and Standards in Public Safety.

Our team (led by consultant Thomas Collingwood) has been active in fitness assessment and standards in public safety organizations for more than 20 years [22, 30, 31, 38]. The focus on developing physical readiness/fitness standards for public safety departments has been on-the-job relatedness of physical fitness. This is because of the legal requirements for having a standard. A standard cannot be based on a health or injury prevention rationale (due to the Americans with Disabilities Act (ADA)), but must be based on the ability of an individual to perform the essential functions of the job. Several trends have been noted in the experience of developing physical fitness standards for hundreds of public safety departments. First is that the fitness areas of aerobic power, upper body and abdominal muscular endurance, lower body strength and power, upper body absolute strength and agility tend to predict the ability to perform the variety of physical tasks required. Of note is that as long as aerobic power and the various muscular strength and endurance areas are accounted for, the measurement of body composition does not add much to the prediction of performing job tasks. In turn, because body composition is not a performance measure and can pose some potential legal issues (because of the ADA) it has not been part of fitness test validation studies for many years.

The many validation studies we have conducted and have been involved with demonstrate that physical fitness factors are job-related and predict the ability of firefighters to perform the essential functions of the job. The focus of those studies was on the job-relatedness of fitness; however, some data were collected noting that back, knee and shoulder were the most prevalent injury areas. However, the relationship of the fitness factors to the incidence and prevention of injuries and other health parameters, such as risk and absenteeism, have never been fully addressed in our validation studies. Although fitness-training programs were recommended as part of the validation process, there were not any formal analyses of the impact of training on health and injury factors. This proposed study will add to our work and supply important data on the relationships between fitness, training, injury and health risk that, coupled with the past validation studies, can provide direction for physical fitness test applications and assessments within fire departments.

B.3.1.4 Intervention Work Specific to Firefighters.

Previously, we conducted a pilot study designed to assess factors that are correlated with successful completion (low elapsed time in the Combat Challenge) for members of the Austin Fire Department's Combat Challenge team. Nine Austin firefighters, men and women (33.0±7.8 years), underwent a four-week period of familiarization on a Concept II Indoor Rower (CII). Subjects' fat-free mass (FFM) was calculated from percent body fat (skinfolds) and body weight. Subjects performed a two-minute maximal bout on the rowing ergometer, rested for 43 minutes, and completed the Combat Challenge. Simple regression analysis revealed that both the average power (AP) during rowing ($r=0.79$, $p=0.012$) and FFM ($r=0.74$, $p=0.023$) were good predictors of time to complete (TC) the Combat Challenge. FFM was also well-associated with AP ($r=0.92$, $p<0.0001$), suggesting that total muscle mass is important for both of these tests. Subsequently, we conducted a heavy resistance-training program for female firefighter applicants three separate times during the years 2002-2006. The express purpose of training these candidates through a heavy resistance weight training program was to increase their lean body mass (FFM) and power, as assessed on maximal lifts in the bench press and leg press. Sixty-six women who were consistent (missing less than two training bouts/month) in their training over the 12-14 week training program, were pre- and post-tested on their maximal bench press and squat. While their maximal strength on these measures varied, their percentage increase in bench press was 15.6% ± 1.3% (mean±SEM) and their increase in maximal squat was 30.1±2.6% (mean±SEM). In the three years that this training was offered to applicants, the passing rate for the Candidate Physical Capacity Test (CPAT) for these women increased from 65% in 2002, to 80% in 2006. The previous record of women passing the CPAT in years prior to this voluntary training program was between 5-15%. These data demonstrate that heavy resistance training significantly enhances strength and ability for women to pass a job-specific Physical Capacity Test. The previous data from members of the Combat Challenge Team of AFD conducted in 1999-2000 demonstrated that FFM was a good predictor of average power, as well as low elapsed time on the Combat Challenge Test.

B.3.2 Overall Strategy

B.3.2.1 Study Design.

The design of the proposed study is an interrupted time-series experimental design of a cluster cross-over trial, and it has two key components. We will observe the association between physical fitness and risk of occupational musculoskeletal injury in firefighters using an interrupted time-series experimental design of data collection of injury data for 2 years:

(i) 6 months pre-intervention,
(ii) 1 year of intervention (cluster cross-over trial), and
(iii) 6 months post-intervention.

The rationale to collect data before and after the intervention is to relate injury data with associated costs which need time to be measured post-intervention. This analysis needs time to be measured and correlated with post-intervention injury data. Second, using a cluster cross-over trial, we will evaluate the effect of a physical training program on the risk of occupationally-related musculoskeletal injury in the firefighters. Based on our success with a strength-training program that we have employed over the last six years for female firefighter applicants, we will extend and implement this approach in the proposed project. We will randomize each of 43 firehouses in the Austin Fire Department (AFD) to either treatment (strength training program) or control (usual activity) for 6 months. The two groups will then be crossed over for an additional 6-month period. Changes in fitness parameters and injury risk will be evaluated during the 12 (6+6) months of intervention. This will allow stations and their firefighters to participate in both their usual forms of exercise, as well as to participate for 6 months in a structured strength-training program. We plan to develop protocols that could be used to maximize and measure compliance with the exercise programs in each group. The design of this proposed intervention study is straightforward and should not adversely affect firefighters.

B.3.2.2 Target Population.

We propose to do this work among full-time firefighters employed by the City of Austin in Austin, Texas. In May 2011, the Austin Fire Department (AFD) employed 973 full-time firefighters, 921 male, 52 female, with a mean age of 39.5. The age range is 22-

54. Race/ethnicity data indicate that 14.8% of the firefighters are of Hispanic/Latino descent, 4.9% are African American and the remainder are Caucasian or of Asian descent with the majority being Caucasian. All firefighters undergo an annual medical examination and undergo a standard fitness assessment at the AFD Wellness Center under the auspices of consultant Paul Parrish, MD, Director of the Wellness Center for AFD.

B.3.3 Methodology

B.3.3.1 Evaluation of Fitness.

As indicated above, the AFD already has an established, ongoing annual fitness assessment program that assesses a wide variety of fitness components. Originally used as a way to promote fitness for the physical demands of firefighting, we propose to use these fitness assessments to prospectively assess the risk of musculoskeletal injuries associated with various fitness parameters. These data provide a rich and unique ability to assess risk of musculoskeletal injury in these firefighters. In addition to general health screening data (resting heart rate, resting blood pressure, height, weight, neck, hip and waist circumferences and % body fat), fitness parameters measured in these evaluations include:

- Aerobic capacity – measured as a maximum aerobic capacity treadmill test (maximum VO_2max test for those under 40 years of age and a submaximal for those over 40 years of age).
- Muscular strength (various components) – Maximum hand grip strength, arm strength and leg strength (dead lift), vertical jump test.
- Muscular endurance – Maximum push-up (to a metronome count), plank hold time.
- Low back and hamstring flexibility – Sit-and-reach test.

B.3.3.2 Injury Risk in Relation to Physical Fitness.

Our goal for Specific Aims 1 and 2 is to evaluate the prospective risk of musculoskeletal injury as it relates to parameters measured in the annual physical fitness testing that is conducted on all AFD firefighters. Because we will have two measurements of physical fitness, we will also assess the association of change in physical fitness parameters with risk of musculoskeletal injury. This will be evaluated during the cluster cross-over trial.

For these Aims, we will first develop the AFD Injury Registry. This will be an injury reporting system that is integrated into the AFD exercise and physical activity log. This system, which has been used for several years, allows firefighters to log their physical activity, exercise and fitness regimen participation information. During the study period, should an injury occur, the firefighter will be asked to indicate that injury in the online system. This indication will trigger a flag, and a visit to the fire station will be scheduled by project staff to determine the extent and severity of the injury. Upon verification of the injury, the firefighter will be advised, based on a severity grading system of 0-4, of remedial measures which can be self-administered, or with grades of 3-4, they will be advised to see their personal physician.

A difficult problem in injury epidemiology is the adoption and use of a consistent and specific definition of what constitutes an injury. For the proposed study, we will adopt the following definition: A bone, muscle, joint or connective tissue injury that is severe enough to make you alter your daily routine, interrupt your work schedule and/or serious enough to seek medical assistance. Injuries meeting this definition will be counted as cases and entered into the AFD Injury Registry.

B.3.3.3 **Strength Training Intervention Program**.

The intervention program will be built from a previously established program in our laboratory, where we worked with female candidates for the AFD. This program will be employed four days per week with instructions for the firefighters to continue their normal physical activity/fitness routine in which they are currently participating. This will be evaluated during the cluster cross-over trial. Study personnel, trained in proper weightlifting techniques, will visit all fire stations that have firefighters participating in the strength training program. The firefighters' intervention techniques will be evaluated by study personnel, and firefighters will be instructed in proper and safe techniques.

The overall flow of the proposed intervention and cross-over program is shown in Figure 1 below.

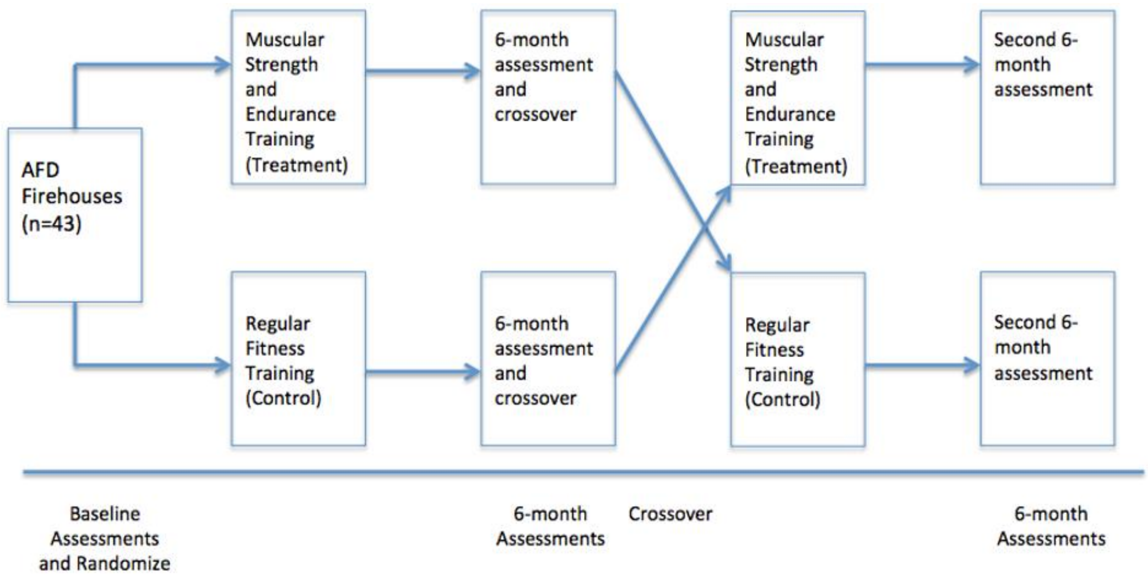

Figure 1. Schematic Flow of Muscular Fitness Intervention in AFD Firefighters.

We will use each firehouse as the unit of intervention. At baseline, the 43 firehouses will be randomly assigned to either the strength training intervention or the control. Each group will be asked to continue their regular fitness and physical activity training. The program will be implemented, with the oversight of Dr. Farrar and his Graduate Research Assistant, for six months with a major data collection point at the three-month period. Each fire station will then be crossed over to the complementary group (Intervention crossed to Control and Control crossed to Intervention). Each group will be followed for an additional six months again with a three-month interim assessment. We chose this particular study design because we are interested not only in training effects of the intervention program, but also any detraining effects that may occur when the initial intervention group is crossed to control. We therefore do not anticipate the need for a "washout" period in this study.

B.3.3.3.1 Protocol.

Most sport scientists and strength coaches interested in maximizing strength and power gains endorse periodization-training methodologies [9]. A periodization training program is a training cycle carried out over a set period of time. During that period of time, however, it seems important to manipulate both the volume (number of sets, number of repetitions, and frequency of training) and the intensity (weights lifted and amount of rest between sets) of the workouts [9]. To this end, we will utilize the following protocol for the strength training intervention. The 6-month program used by the firefighters will be broken down into the following divisions:

Week 1: Physical testing, resistance training instruction, and orientation
Weeks 2-7: Hypertrophy/Conditioning Phase [High volume/Relatively Low Intensity]
Weeks 8-10: Basic Strength [Moderate Volume/Moderate Intensity]
Weeks 10-12: Peaking [Low Volume/High Intensity]
Week 13: Strength Assessment and Fitness Assessment
Weeks 13-19: Hypertrophy/Conditioning Phase [High volume/Relatively Low Intensity]
Weeks 20-22: Basic Strength [Moderate Volume/Moderate Intensity]
Weeks 23-25: Peaking [Low Volume/High Intensity]
Weeks 26-27: Testing

This program will be organized around the target set system. This means that in those workouts deemed "heavy", the candidates will be asked to do two or, usually, three "target" sets with as heavy a weight as they can handle and still properly perform the repetitions. For example, on a heavy day in the squat in the hypertrophy phase, the firefighter might warm up with 85 pounds in the squat and then do three sets of ten repetitions with 125 pounds. If the weight has been properly chosen, the firefighter should barely be able to perform the final reps of the third set. Most major lifts will be performed twice a week with a light/heavy approach. On “light days” the firefighter will lift approximately 85-90% of the weight used in the previous heavy workout (The firefighter who did 125 pounds for three sets of ten on her heavy day would warm up with 75 pounds and then do three sets of ten with approximately 110 pounds.) Firefighters will work out four days a week. For example, Mondays and Thursdays will be devoted to upper body weight training exercises and running, stair climbing and agility-strength work. Tuesdays and Fridays will be devoted to leg, low back, abdomen and torso work. *A sample weekly protocol is included in the Appendix.*

The strength training protocols will be implemented in each fire station under the supervision of Dr. Farrar and his Graduate Research Assistant (GRA). Each facility has a complete set of weight training equipment on site, making it very convenient for the firefighters to participate. Trainings will be conducted by study personnel at each fire station prior to the beginning of each intervention. All fire stations will be visited on a regular, rotating basis and firefighter workouts will be monitored by the GRAs. The resistance training will occur 1-2 hours before they go on their shift, approximately 10:00-11:45 AM, and at the end of their shift the next day between 12:30 and 2:00 PM. This schedule will allow for two consecutive workouts with a 48-hour rest period before their next set of workouts. These workouts will then be bracketed around the 24-hours on/48-hours off schedule of the firefighters. Any firefighters with pre-existing conditions that result in contraindications for participation in strength training will be excluded from the strength training intervention.

With assistance from the AFD Wellness Department, we will schedule meetings with each station commander and all aspects of the study will be explained. We will then meet with groups of firefighters at each station, again to explain the goals of the study and to answer any questions. Informed consent will be obtained at this time and participants will be enrolled.

B.3.3.3.2 Measures.

A key outcome for this intervention cross-over study is changes in muscular strength and power (lower and upper body) from baseline. At baseline and again at 6 months (before and after the crossover), we will use the following testing regimen: For lower body strength and power, we will use the squat test and standing vertical jump. For upper body strength and power, will we will use the chin-up test, bench press, latissimus dorsi pull-down, and chair dips. Each test will be monitored by study personnel to assure that the chin-ups, dips, and latissmus dorsi pull downs are performed correctly (e. g. full range for each repetition), and the bench press will be monitored to standard power lifting protocols for a valid bench press. Similar standards will be utilized to evaluate vertical jump and squat. All GRAs will be trained in proper technique evaluation and will judge all performance measures.

We also propose to measure body composition in all firefighters before and after the intervention. This will be accomplished in our facility at the University of Texas at Austin, where we have substantial experience conducting these tests. Body composition will be determined from DXA technology using a Lunar Prodigy (G. E. Medical Systems, Madison, WI). All selected data will be analyzed with enCORE software (version 11.0). Each Firefighter will wear light exercise clothing and remove all metal jewelry, plastic, and rubber materials that could affect the X-ray beam. Quality control and bone mineral calibration will be performed using a spine phantom made of calcium hydroxyapatite and embedded in a lucite block. Scans of the phantom spine will be recorded every other day according to the manufacturer's guidelines. The bone mineral density values obtained from calibration have previously been shown to be stable, (mean= 0.993 g/cm2, CV = 0.09%) [39].

B.3.3.3.3 Injury Assessment.

Another key outcome for the intervention study is the incidence of musculoskeletal injuries and comparing that incidence between treatment and control groups. Injuries will be defined as indicated previously for the Injury Registry. We (Dr. Kohl and his post-doctoral fellow) will use the AFD Injury Registry (described above) to ascertain musculoskeletal injuries in participants and controls for the duration of the study. This system will not only be used for the 6-month follow-up (pre- and post-crossover) but also to monitor the safety of firefighters participating in the strength training intervention.

B.3.3.3.4 Process (Fidelity) Measures.

Although every effort will be made to ensure full compliance with the strength training protocols, it is likely that there will be variance in participation across the fire stations. This variability could be due to leadership (fire station captain being very supportive or not supportive at all) and to individual factors (illness, loss of interest, etc.). We are aware that this will be a challenge, and we will therefore develop protocols and tools to measure the fidelity of implementation at each fire station. Key measures will include ratings of subject and objective assessments of leader support, exercise training participation rates (from online reporting system) and individual firefighter support for the program.

B.3.3.3.5 Data Safety and Monitoring Plan.

As part of this project, we will develop a comprehensive Data Safety and Monitoring Plan (DSMP). Although the risk is minimal, injuries due to the participation in the strength training program are possible. Our pilot study experience suggests that injuries due to the strength training are rare. For the study, we will monitor the incidence of injuries from our Injury Registry methods (outlined previously). Should an excess of injuries seem to be occurring particularly by fire station, the DSMP will detail appropriate actions. For the individual firefighters, we will monitor any injuries that may occur during the intervention of STP. Brian Farr, Head of Athletic Training Academic Program and former athletic trainer for the University of Texas, Oklahoma State, Ohio State, and Board Certified Athletic Trainer, will review any reported injuries gathered by the GRAs and/or self-reported by the AFD firefighters. Mr. Farr will visit all fire stations on a regular basis to evaluate any injuries and make recommendations for remediation. Any injuries that are classified as grade 3 or 4 will be referred to a physician of the firefighter's choice if the firefighter has not already sought medical care.

As part of Mr. Farr's duties on the project, he will visit all firehouses on a scheduled basis to provide review of proper technique in lifting as well as preventive measures to reduce incidence of injury. Mr. Farr will also provide presentations to the AFD on a quarterly basis with regard to guidelines and practices to minimize injury occurrence in workouts or on the job activities.

B.3.3.4 Return on Investment.

Consultant H. Shelton Brown is a health economist and will advise on the return on investment analyses. To accomplish this, we will calculate work time lost due to occupational injury (workman's compensation claims, absenteeism, and reduced-duty time) from AFD administrative records. We will also calculate medical care claim costs due to injury treatment and rehabilitation (doctor visits and physical therapy). These data are available in AFD administrative records. We will then compare the costs of the musculoskeletal intervention with the medical care and lost duty time costs to determine the potential return on investment.

B.3.3.5 Outcome Measures.

A summary of outcome measures, the period of the study in which those measures will be taken, and tests used to assess the measures are shown in the table below:

Study	Period	Measure	Test(s)
Fitness and risk of injury	Baseline	Physical fitness measures (aerobic capacity, upper and lower body strength and endurance, flexibility)	Treadmill testing, push-ups, hand grip strength, plank hold, vertical jump, dead lift
	Throughout	Musculoskeletal injury	Incidence
	Follow-up	Physical fitness measures (aerobic capacity, upper and lower body strength and endurance, flexibility)	Treadmill testing, push-ups, hand grip strength, plank hold, vertical jump, dead lift
Strength training intervention	Baseline	Upper and lower body muscle strength and endurance, body composition, aerobic capacity	1 RM bench press, 1 RM squat press, push-ups, hand grip strength, plank hold, vertical jump, dead lift, treadmill test
	3-month interim	Physical activity, injury	Physical activity logs, injury registry
	6-month follow-up	Upper and lower body muscle strength and endurance, body composition, aerobic capacity, physical activity, injury	1 RM bench press, 1 RM squat press, push-ups, hand grip strength, plank hold, vertical jump, dead lift, treadmill test, physical activity logs, injury registry
Return on investment	Baseline	Medical care claims, absenteeism, reduced duty assignments	Insurance records, attendance logs, job assignments
	6-month follow-up	Medical care claims, absenteeism, reduced duty assignments	Insurance records, attendance logs, job assignments

Table 2. Summary of Outcome Measures.

B.3.3.6 Data Analysis

Specific Aim 1. We will estimate the person-time-injury incidence in this population, including in the numerator subjects with one or more injuries divided by the total number of days in training. Then, we will estimate people injured per 100 person-days. Survival analysis will be implemented to compute estimates and 95% confidence intervals associated with each trial arm. Univariate and multivariate analysis of potential risk factors will be performed using Cox proportional hazards models for cluster randomized cross-over trial [40].

Specific Aim 2. We will determine the association between changes in physical performance measures (upper and lower body strength) and risk of injury using either mixed models with cluster effects or generalized estimating equations for cluster randomized trials depending on the goodness of fit of the outcome variables [41, 42].

Specific Aim 3. Frequency distributions and summary statistics of primary and secondary outcomes (e.g., demographic factors, injuries, fidelity of training, physical activity scores, physiological variables, fitness, etc.) will be described for the cohort and the cluster randomized cross-over trial. Weekly physical activity from the diary will be compared with the intervention (training) and the control (usual activity). This descriptive analysis will include frequency distributions, as well as measures of central tendency (means and medians) and measures of variability (standard deviations and inter-quartile ranges). We will test the assumption of normality and transform the weekly average if the normality assumption is not met using Box-Cox transformations.

Specific Aim 4. We will estimate ROI, or the excess of averted medical costs and averted productivity costs, or absenteeism, as compared to the cost of the intervention. The mathematical formula for ROI is simple. In the denominator lies the costs of the intervention. In the numerator lies the averted medical cost or productivity costs, taking present value of future averted costs. If the estimated ROI ratio is above one, the investment at least breaks even. In a trial situation, averted medical costs are the reduction in costs in the intervention group versus the trial; averted productivity costs are the reduction in lost days in the intervention group versus the control. The lost days are valued in terms of wages, which is what is needed to replace absent workers. Averted labor costs will be gathered from timecard records in conjunction with the injury log, described earlier, to ensure the injuries are PA-related. Medical costs will be derived from the injury surveillance system, with the costs of averted medical costs coming from Walton et al. (2003).

B.3.3.7. Sample Size and Power.

We estimated the power for estimating the person-time injury incidence rate for the cohort (Aim 1). Regarding sample size, we estimate that only 70% of AFD's 973 firefighters will accept to participate in the cluster randomized cross-over trial. This estimate accounts for attrition - those who drop out or whom we're unable to follow. Therefore, we estimate to include 680 firefighters in the study, who will be equally distributed among the 2 cluster arms in two times (pre-cross-over and post-cross-over). We are planning a pre-cross-over study with 241 experimental subjects, 241 control subjects and type I error level of 0.05. We estimated 1 person injured/100 person days without the training program. If the true relative risk is 1.3, we will be able to reject the null hypothesis that the experimental and control survival curves are equal with probability (power) 0.821. If we observe larger relative risk than 1.3, we will have even more power. This indicates that we will have enough number of events to compare the incidence rates [43]. The second power calculation was needed for Aim 2, seeking to detect differences in treatment effect in terms of the relative risk of injury on physiological variables. The upper and lower body static strength used were pilot data reported by Knapik et al. (2001). The intraclass correlation coefficient (clustering effect) of the fire stations was estimated at 0.9. Several interperiod correlations (induced by the cross- over design) are presented in the table below for various estimated standard errors of the relative risks (Knapik et al. 2001), assuming a difference in relative risk between training and usual care of 0.5. We computed the required number of cluster (fire stations), assuming a total of 680 firefighters participating in the cluster, randomized cross-over trial and type I error of 0.05 for power of 90% and 80%.

		Upper Body static strength				Lower Body static strength			
		SE				SE			
Power	η	0.92	1.15	1.38	1.61	0.61	0.77	0.92	1.07
0.9	0.1	57	50	42	35	25	22	19	16
	0.2	50	42	35	28	22	19	16	13
	0.3	42	35	28	21	19	16	13	9
	0.4	35	28	21	14	16	13	9	6
	0.5	28	21	14	7	13	9	6	3
0.8	0.1	42	37	32	26	19	16	14	12
	0.2	37	32	26	21	16	14	12	9
	0.3	32	26	21	16	14	12	9	7
	0.4	26	21	16	11	12	9	7	5
	0.5	21	16	11	5	9	7	5	2

Table 3. Upper and Lower Body Static Strength Data Reported by Knapik et al. 2001.
SE: standard error or relative risk; η= interperiod correlation.

The total number of fire stations in Austin is 43, and we will invite all to participate into this cluster, randomized cross-over trial. For this reason, we believe we will have enough power to detect a meaningful difference in the relative risk of injury and on-the-strength variables.

B.3.4. Timeline.

A projected timeline (by quarter) for the proposed study is presented below. Injury surveillance and analyses with fitness measures will be ongoing throughout the study after a 6-month start-up period. For the intervention study, we anticipate needing six months to complete baseline assessments and enrollment with the final measurements occurring in the 10th quarter of the study. The bulk of the return on investment analyses will occur in the final year of the project.

	Calendar Quarter (3 years total)											
	1	2	3	4	5	6	7	8	9	10	11	12
Start-up, hire project staff, establish project office												
Develop and test strategies for establishing injury registry & surveillance												
Implement injury registry and surveillance												
Annual fitness assessments												
Analyses on fitness and risk of injury												
Develop and refine protocols for strength training intervention and data collection												
Randomize fire stations												
Intervention study												
Major data collection points in intervention study												
Data analyses in intervention study												
Develop and refine protocols for return on investment analyses												
Data collection and analyses on return on investment												
Manuscript preparation												
Project closeout												
Report of results, written with verbal presentation of recommendations, to AFD												

Table 4. Projected Timeline by Calendar Quarter.

References

1. Sothmann, M.S., et al., *Heart rate response of firefighters to actual emergencies. Implications for cardiorespiratory fitness.* J Occup Med, 1992. 34(8): 797-800.
2. Swank, A.M., et al., *Age-related aerobic power in volunteer firefighters, a comparative analysis.* J. Strength Cond Res, 2000. 14: 170-174.
3. Gledhill, N. and V.K. Jamnik, *Characterization of the physical demands of firefighting.* Can J Sport Sci, 1992. 17(3): 207-213.
4. Karter M.J. and J.L. Molis. *US firefighter injuries – 2012*. National Fire Protection Association 2012 [cited 2014 February].
5. United States Bureau of Labor Statistics, *Incidence rates of nonfatal occupational injuries and illnesses by industry and case types*, 2011, www.bls.gov
6. Jones, B.H., M. Canham-Chervak, and D.A. Sleet, *An evidence-based public health approach to injury priorities and prevention recommendations for the U.S. Military.* Am J Prev Med, 2010. 38(1 Suppl): S1- 10.
7. Rhea, M.R., B.A. Alvar, and R. Gray, *Physical fitness and job performance of firefighters.* J Strength Cond Res, 2004. 18(2): 348-352.
8. Michaelides, M.A., et al., Assessment of physical fitness aspects and their relationship to firefighters' job abilities. J Strength Cond Res, 2011. 25(4): 956-965.
9. Kraemer, W.J., et al., *American College of Sports Medicine position stand. Progression models in resistance training for healthy adults.* Med Sci Sports Exerc, 2002. 34(2): 364-380.
10. Sprague, R.C.T., et al., *Force-velocity and power-velocity relationships during maximal short-term rowing ergometry.* Med Sci Sports Exerc, 2007. 39(2): 358-364.
11. Martin, J.C., et al., *Maximal power across the lifespan.* J Gerontol A Biol Sci Med Sci, 2000. 55(6): M311-6.
12. National Fire Protection Association. *NFPA 1583 standard on health-related fitness programs for fire fighters.* in *NFPA*. 2000. Quincy, MA.
13. Roberts, M.A., et al., *Fitness levels of firefighter recruits before and after a supervised exercise training program.* J Strength Cond Res, 2002. 16(2): 271-277.
14. Brock, J.R. and S.J. Legg, *The effects of 6 weeks training on the physical fitness of female recruits to the British army.* Ergonomics, 1997. 40(3): 400-411.
15. Dennison, K.J., et al., *The effect of fatigue and training status on firefighter performance.* J Strength Cond Res, 2012. 26(4): 1101-1109.
16. MacKinnon, D.P., et al., *Long-term effects of a worksite health promotion program for firefighters.* Am J Health Behav, 2010. 34(6): 695-706.
17. Davis, P.O., C.O. Dotson, and D.L. Santa Maria, *Relationship between simulated*

firefighting and physical performance measures. Med Sci Sports Exerc, 1982. 14: 65-71.

18. Jackson, A., *Pre employment physical evaluation.* Exercise Sports Sci R, 1994. 22: 53-90.
19. Peate, W.F., et al., *Core strength: a new model for injury prediction and prevention.* J Occup Med Toxicol, 2007. 2:3.
20. Cybex. *Firefighter Fitness Facts*. 2010 [cited December 7, 2010; 1].
21. Cady, L.D., et al., *Strength and fitness and subsequent back injuries in firefighters.* J Occup Med, 1979. 21(4): 269-272.
22. Hoffman, R. and T. Collingwood, *Fit for Duty* 2005, Champaign, IL: Human Kinetics Publishing.
23. Jahnke, S.A., et al., *Injury among a population based sample of career firefighters in the central USA.* Inj Prev, 2013. 19: 393-398.
24. Jones, B.H., et al., *Epidemiology of injuries associated with physical training among young men in the army.* Med Sci Sports Exerc, 1993. 25(2): 197-203.
25. Knapik, J.J., et al., *Risk factors for training-related injuries among men and women in basic combat training.* Med Sci Sports Exerc, 2001. 33(6): 946-954.
26. Hoffman, J.R., et al., *The effect of leg strength on the incidence of lower extremity overuse injuries during military training.* Mil Med, 1999. 164(2): 153-156.
27. de Loes, M. and B.R. Jansson, *Work-related injuries from mandatory fitness training among Swedish firemen.* Int J Sports Med, 2001. 22(5): 373-378.
28. Blair, S.N., et al., *Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men.* JAMA, 1995. 273(14): 1093-1098.
29. Karter, M.J., *U.S. Fire Department Profile through 2001*, in *National Fire Protection Association* , 2002.
30. Hoffman, R., T. Collingwood, and J. Smith, *Validation Report: Physical Readiness Standards for theKilleen Fire Department*, 2007: Killeen, Texas.
31. Collingwood, T., *Validation Report: Physical fitness standards for the Addison Fire Department.*, 1999, Addison Fire Department: Addison, TX.
32. National Institute of Standards Technology. *The Economic Consequences of Firefighter Injuries and Their Prevention.* in *US Department of Commerce*. 2005. Washington D.C.
33. Seabury, S.A. and C.F. McLaren. *The Frequency, Severity, and Economic Consequences of Musculoskeletal Injuries to Firefighters in California*. Rand Center for Health and Safety in the Workplace 2010 [cited 30 May 2011; Available from: www.rand.org
34. Gordon, N.F., et al., *Cardiovascular safety of maximal strength testing in healthy adults.* Am J Cardiol, 1995. 76(11): 851-853.

35. Kohl, H.W., III, et al., *A controlled trial of physical activity interventions: design, and baseline data from Project Active.* Med Sci Sport Exerc 1998. 30(2): 275-283.

36. Dunn, A.L., et al., *Improvements in physical activity and physical fitness in 235 initially sedentary men and women: 6 month results from Project Active.* Med Sci Sports Exerc, 1998. 30(7): 1076-1083.

37. Dunn, A.L., et al., *Comparison of lifestyle and structured interventions to increase physical activity andcardiorespiratory fitness: A randomized trial.* JAMA, 1999. 281(4): 327-334.

38. Collingwood, T., R. Hoffman, and J.E. Smith, Jr., *Validation Report: Physical Readiness Standards for the Sugar Land Fire Department.* 2006: Sugar Land, Texas.

39. Pepper, M.R., et al., *Validation of a 3-dimensional laser body scanner for assessment of waist and hipcircumference.* J Am Coll Nutr. 29(3): 179-188.

40. Graubard, B.I. and E.L. Korn *Regression analysis with clustered data.* Stat Med, 2006. 13: p. 509-522.

41. Donner, A. and N. Klar, *Design and Analysis of Cluster Randomization Trials in Health Research.* Hodder Arnold Publication, 2000.

42. Braun, T., *A mixed model-based variance estimator for marginal model analyses of cluster Randomized trials.* Biometrical J, 2007. 49(3): 394-405.

43. Schoenfeld, D.A. and J.R. Richter, *Nomograms for calculating the number of patients needed for a clinical trial with survival as an endpoint.* Biometrics, 1982. 38: 163-170.