ABSTRACT

Title: **PHYSIOLOGICAL DETERMINANTS OF THE CANDIDATE PHYSICAL ABILITY TEST IN FIREFIGHTERS**

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The purpose of this study was to examine the relative importance of physiological characteristics during firefighting performance, as assessed by the Candidate Physical Ability Test (CPAT). Participants included professional and volunteer firefighters, ages 18-39 (n=33). Muscle strength, muscle endurance, muscle power, body composition, aerobic capacity, anaerobic fitness, and the cardiovascular response to stairclimbing were assessed to determine the physiological characteristics of the participants. To quantify firefighting performance, the CPAT was administered by members of the fire service. Absolute and relative mean power during Wingate anaerobic cycling test (WAnT), relative peak power during WAnT, and absolute maximal oxygen uptake (VO_2max) were significantly higher in those who passed the CPAT (n=18), compared to those who failed (n=15) ($P < 0.01$). Absolute and relative mean power during WAnT, fatigue index during WAnT, absolute VO_2max, upper body strength, and the heart rate response to stairclimbing were all significantly related to CPAT performance time (all $P < 0.01$). However, absolute VO_2max and anaerobic fatigue resistance during WAnT combined were the best predictors of total CPAT performance (Adj. $R^2 = 0.817$; $P < 0.001$).

Performance on the ceiling breach and pull was the only individual CPAT task that could not be significantly predicted by the physiological characteristics assessed. Rate-pressure product during the stairclimb was not related to CPAT performance. In conclusion, measures of anaerobic and aerobic fitness best predict overall CPAT performance, as well as individual task performance. Remedial programs aimed at improving firefighting performance should target anaerobic and aerobic fitness qualities.

PHYSIOLOGICAL DETERMINANTS OF THE CANDIDATE PHYSICAL ABILITY TEST IN FIREFIGHTERS

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Introduction

The physical demands of firefighting, as an occupation, are characterized by significant activation of the cardiovascular, metabolic, and endocrine systems. Heart rates in excess of 95% of maximum (53, 55, 72, 74, 89, 92), rates of oxygen consumption approaching maximal oxygen uptake (VO_2max) (10, 34, 89, 92), and significant activation of the sympathoadrenal axis (64, 76) have been recorded during simulated or live firefighting tasks. Thus, fire fighting suppression activities may be a significant physiological stress and high levels of fitness are required by the firefighter. Although the generalized physiological reactions to fighting fires have been investigated, the physical attributes and fitness components required for optimal firefighting performance have not been fully identified. For this reason, it has been difficult to design appropriate remedial intervention programs that make optimal improvements in the qualities most important for firefighting performance. Previous studies on firefighters have assessed factors most closely aligned with steady state work/exercise, i.e., aerobic metabolism (10, 23, 25, 66, 74, 89), while little is known about the role of anaerobic energy sources during firefighting tasks (92).

Several studies have correlated physical attributes with performance in individual firefighting-related tasks (16, 65, 89, 93). In these studies, muscle strength (65, 89, 93), body composition (93), absolute VO_2max (89), and muscle endurance (65, 93) are significantly related to task performance. Cardiovascular fitness predicted performance in one study (93), but failed to do so in another (65), raising questions as to the relative importance of cardiovascular fitness for firefighting performance. Stairclimbing tasks in full gear have been shown to elicit heart rates of 95% of maximum and rates of oxygen consumption equivalent to 80 % of VO_2max (61).

Intense muscular exertions in firefighters with compromised cardiovascular systems can precipitate cardiac events when the heart's demand for oxygen (myocardial oxygen demand) exceeds its oxygen supply capabilities. The product of heart rate and systolic blood pressure (RPP) offers a reliable index of myocardial oxygen demand and serves as an indicator of the cardiovascular and metabolic stress placed on the heart during strenuous activity. Reducing the RPP response to firefighting tasks may reduce the risk of a cardiac event in predisposed firefighters, by lowering the cardiovascular and metabolic stress on the heart during the task. However, no information is available on the fitness and body composition components that are most closely associated with a low RPP response to firefighting tasks.

While most studies have examined the dynamics of heart rate and oxygen uptake during firefighting performance, some have observed substantial elevations in peak lactate values (34, 89), as well as varying oxygen demands (34), elevated respiratory exchange ratios (92), and heart rates (23, 67) among different tasks. Coupled with the inherently unpredictable nature of emergency situations, the data suggest that firefighting is an intermittent, non-steady state activity. Despite the apparent importance of anaerobic fitness, limited research has been done to clarify the relationship between muscular power and firefighting performance. One study examined the importance of muscular power, as measured by the standing long jump, to firefighting tasks (16). More recently, another study found a moderate relationship between peak power during WAnT and firefighting performance (92). Anaerobic endurance, as measured by 400m run, was also reported to be positively related to firefighting task performance (65). Thus, there is a need to clarify the relative influence of aerobic versus anaerobic fitness to firefighting performance.

Few studies have examined the relationship between fitness and integrated firefighting tasks. In this context, the Candidate Physical Ability Test (CPAT) is a nationally established firefighting simulation test, which is currently employed by many fire departments throughout the country to screen applicants. Yet, information is lacking on the relative contribution of the various physical or functional attributes that determine optimal CPAT performance.

Characterization of the physiological variables contributing to CPAT performance can potentially improve the application process. The establishment of the minimal physical capacities necessary to successfully complete CPAT can potentially result in significant financial savings through an improved screening process (11). Additionally, by further clarifying the physiological determinants of CPAT performance, the fitness requirements for optimal firefighting performance can be established and applied to create training programs capable of improving CPAT, and ultimately, improving firefighting performance.

Williams-Bell et al. (92) recently reported on the physiological demands of CPAT through the use of portable metabolic analysis. Respiratory exchange ratios in excess of 1.0 were demonstrated during CPAT, suggesting significant activation of anaerobic metabolism. Absolute VO_2max during treadmill running was able to explain 57% of the variation in CPAT performance. However, the subjects studied were not firefighters, order and fatigue effects were not controlled, body composition was not measured, and only indirect assessments of muscular strength were implemented in this investigation. Consequently, there is a need to further examine these parameters in firefighters while attempting to control for the influence of fatigue on sensitive such, such as strength, power, and anaerobic capacity.

Therefore, the purpose of this study was to examine the relative importance of several physiological variables during CPAT performance in active firefighters, while controlling for order and fatigue effects of testing. Because of the intermittent nature of fighting fires, it is hypothesized that physical attributes, such as muscular strength, power, and anaerobic power are better predictors of CPAT performance than aerobic capacity.

Research Hypotheses and Significance

Research Hypotheses

1. Anaerobic fitness (anaerobic capacity and muscle power) , aerobic capacity, body composition, upper body strength, lower body strength, peak heart rate following stair climbing , and percentage of maximal heart rate achieved during stair climbing will each be significantly correlated to CPAT performance. Anaerobic fitness and muscular strength combined will be a significantly better predictor of CPAT performance than any of the other individual factors alone.

2. Lower body strength, followed by aerobic capacity and body composition, will be significantly related to the rate-pressure product achieved during a stair climbing task.

3. Differences in anaerobic fitness, aerobic capacity, body composition, upper body strength, lower body strength, peak heart rate in response to stair climbing, and percentage of maximal heart rate achieved during stair climbing will account for successful completion of the CPAT, with measures of anaerobic fitness and strength being of greater importance.

Significance

The results of this study will serve to better characterize the physiological attributes that best determine firefighting performance as assessed by the CPAT. This may be useful in combination with other studies for future development of optimal training interventions for improving firefighting performance. This information may also be helpful for developing more optimal, efficient, and fiscally prudent screening processes.

Methods

Subjects: Thirty-three volunteer and career firefighters, ages 18-45, from Baltimore-Washington metropolitan area fire departments volunteered to participate in a 5 day testing battery. Subjects were actively recruited by the Maryland Fire and Rescue Institute (MFRI) through the use of flyers, internet advertising on the MFRI website, and in-person recruitment visits to local fire departments. After the methods and procedures of the study were explained, all subjects signed a consent form approved by the Institutional Review Board of the University of Maryland, College Park. All subjects had no more than 2 risk factors for cardiovascular disease as determined by guidelines set forth by the American College of Sports Medicine (2). A minimum of 1 day of rest separated each day of testing in order to minimize fatigue.

Design/Variables: This research project utilized a cross-sectional design. The study sought to determine the physiological characteristics which are correlated with and predict firefighting performance. In this case, the various physiological characteristics acted as independent variables, and include body composition (% body fat & fat free mass), aerobic capacity, peak anaerobic power and mean anaerobic power, muscle power, muscle endurance, and strength. Firefighting performance, as assessed by the CPAT, was the dependent variable.

One-repetition maximum (1-RM) strength: Air-powered resistance training machines (Keiser A-300 Leg Extension machine, Chest Press machine, Leg Press machine, Keiser Sports/Health Equip. Co., Inc., Fresno, CA) were used to test 1-RM. 1-RM strength testing has been shown to have a test-retest reliability of r = 0.98 (91) to 0.99 (45). The test measures the amount of force the exercised muscles can exert in a given movement pattern. The 1-RM is considered to be the reference standard for the measurement of maximal strength by the American College of Sports Medicine (1).

The 1-RM strength testing was performed bilaterally on the chest and leg press, and unilaterally on the knee extension exercise. For all strength tests, subjects were familiarized to the testing equipment between 2 and 5 days prior in order to account for the effects of motor learning (skill acquisition) on performance. The estimated 1-RM was determined as a percentage of bodyweight. Chest press 1-RM was 75% of bodyweight, knee extension was equal to bodyweight, and leg press was equal to 3 times bodyweight. The familiarization consisted of 4 sets at varying percentages of the estimated 1-RM. The first set was performed for 10 repetitions with no resistance and the second set was performed for 8 repetitions at 10% of estimated 1-RM. The third set was performed for 5 repetitions at 30% of estimated 1-RM and 3 repetitions at 50% of the estimated 1-RM were performed for the fourth set.

For all strength tests, subjects completed 2 minutes of seated cycling as a warm-up. Testing proceeded with single repetition sets and 1 minute rest between each set. After each trial they provided a number on the Pain/Discomfort and Rating of Perceived Exertion scales. The resistance increased in a manner that allowed for the determination of 1-RM within 8 to 10 trials.

For the leg press, the subjects were seated on the machine with the seat positioned so that the knee joint forms a 90 degree angle. They were instructed to place their arms across their chest and to breathe normally. A successful repetition was counted when the knee was fully extended. For the chest press, subjects were seated in a position that aligned the handlebars with the xyphoid process. Subjects were instructed to keep the head and back against the back pad and their feet flat on the floor. A successful repetition was achieved when the elbows were fully extended. For the knee extension exercise, each leg was tested separately, with the right leg tested first. The seat was positioned so that the axis of rotation of the knee joint lined up with the axis of rotation of the knee extension machine. Subjects were instructed to cross their hands across their chest and breathe normally. A restraint was placed across the subject's lap in order to restrict movement of the hips. A successful repetition was achieved when the knee joint angle exceeded 165 degrees, as assessed by an indicator light when this angle was reached.

Muscle Endurance: The Keiser A-300 Chest Press machine and Leg Press machine were used to test muscle endurance. A maximal repetition test against a pre-determined percentage of strength was used to determine muscular endurance, as endorsed by American College of Sports Medicine as a valid measure of muscular endurance (1). The test measures fatigue resistance with a reliability index of greater than $r = 0.97$ in a previous study (56).

Muscle endurance in the chest press and leg press exercises were assessed directly after the achievement of a 1-RM in the respective movement. A 5 minute rest period was taken after the final trial of the 1-RM testing process. The same seat position was used for both 1-RM and muscle endurance testing. Subjects completed as many repetitions as possible with 80% and 70% of the 1-RM in the leg press and chest press, respectively. The same criteria were used to determine a successful repetition as during 1-RM testing, with the addition that the subject must completely return to the starting position at the conclusion of each repetition. They were instructed to breathe normally, ensure a full range of motion, and to move continuously. Pausing between repetitions resulted in the termination of the test. The total number of repetitions was recorded.

Muscle Power: An air-powered resistance training machine (Keiser A-300 Leg Extension machine, Keiser Sports/Health Equip. Co., Inc., Fresno, CA) was used to test for muscle power. Additionally, a computer program (A430 version 1.6.0.19 (2003), Keiser Sports/Health Equip. Co., Inc., Fresno, CA) was used to measure muscle power in watts. Subjects completed a 5 minute warm-up on a cycle ergometer prior to power testing, which was performed on an air-powered knee extension resistance machine. The Keiser machine measures maximal movement velocity and force production to calculate muscle power in watts, using a specialized timing device and load cell. Muscle power testing was shown to be both reliable and valid in a previous study using similar equipment, with an intra-class correlation coefficient of 0.91 (13).

A single practice trial was performed at 30% of the previously established unilateral 1-RM prior to muscle power testing at 50%, 60%, and 70% of the previously determined 1-RM for each leg. Three sets of a single repetition were performed at each resistance. For each trial, subjects were instructed to extend the knee as fast and as hard as possible. For each set, the right leg was tested and immediately followed by the left leg. A 1 minute rest period was taken between sets at the same percentage of 1-RM. After all 3 sets were completed for a given percentage of 1-RM, a 2 minute rest was taken prior to the next series of tests. Test results were recorded using a software program from Keiser Sports/Health Equipment Co. Muscle power was tested on 2 separate occasions, with approximately 3-5 days in between. The higher of the 2 values was used, as this value would represent peak power.

Peak Anaerobic Power, Mean Anaerobic Power, and Fatigue Index: A Wingate Anaerobic Cycling Test (WAnT) was administered using a cycle ergometer (Monark 824E) to determine a fatigue index, maximal anaerobic power, and mean anaerobic power. Reliability for peak anaerobic power and mean anaerobic power range from 0.95 to 0.98 (27, 44, 46). The validity of the WAnT is based upon correlations between physiological measures and performance measures. Peak anaerobic power and mean anaerobic power, as measured by WAnT, have been shown to be correlated with the percentage of fast-twitch muscle fibers, as well as the total area of fast-twitch fibers (46). Additionally, peak anaerobic power has been shown to be significantly related to a 50m run ($r = -0.91$) (46).

Subjects pedaled with no resistance for 3 minutes, followed by a pair of 5-second practice sprints separated by approximately 30 seconds of active recovery with no resistance. Following the second practice sprint, they rested passively for 2 minutes while remaining on the bike. After 2 minutes had elapsed, they pedaled slowly for 30 seconds, followed by pedaling as fast as possible for 30 seconds against a resistance equivalent to 7.5% of bodyweight. The number of revolutions completed in each 5 second period was recorded over the course of the 30 second test. The test concludes with 5 minutes of slow pedaling with no resistance.

Aerobic Capacity: A treadmill (Trackmaster), Douglas bags, and a mass spectrometry unit (Perkin-Elmer) were used to determine maximal oxygen uptake (VO_2max). Subjects wore a mask that collects all gas expired through the mouth. The nose was clipped to ensure that all air was exhaled through the mouth. A hose connected the mask to a leak-proof bag where the gas was collected for standardized periods of time. The volume of oxygen consumed was determined by measuring the volume of expired air in each Douglas Bag and the composition of the exhaled gas, assessed by the mass spectrometer (22).

A graded treadmill exercise protocol was used in which a treadmill speed was determined that elicited a heart rate equivalent to 85% of age-predicted maximal heart rate. This speed was designated as the speed at which the test was conducted and was kept constant throughout the test. After appropriate warm-up, the treadmill speed was increased to the predetermined testing speed. The grade of the treadmill started at 0% incline and was increased by 2% every 2 minutes thereafter until volitional fatigue was achieved. Heart rate was recorded every 2 minutes. The highest oxygen uptake recorded was considered to be VO_2max. A test was considered valid if an RER in excess of 1.10 or a heart rate in excess of age-predicted maximum was recorded.

Body Composition: Body composition was assessed through the use of dual-energy x-ray absorptiometry (DEXA) scanning using fan beam technology (model QDR 4500A, Hologic, Waltham, MA). The coefficients of variation were determined by scanning 10 subjects in triplicate, with each subject repositioned between scans. The CV was 0.6 % for FFM and 1.0% for percent fat (17). As a measure of criterion-referenced validity, fat-free mass as measured by DEXA was significantly correlated fat-free mass measured with computer topography (R_2=0.98) (88). The DEXA scanner was calibrated through the use of a spine phantom scan, step phantom scan, and whole body phantom scan prior to testing. The subjects were measured for height and weight to the nearest 0.1 cm and 0.1 kg prior to scanning and positioned supine on the table. Scans were analyzed with the Hologic analysis program.

Cardiovascular Responses to Stair-Climbing: The cardiovascular responses to stair-climbing were determined through the use of a Stairmaster step mill and a Tango blood pressure and heart rate unit. Prior to testing, 3 electrodes were placed on the subject's chest at V_2, V_6, and the right limb ground position. Subjects wore a 50 pound weight vest and completed a 2 minute warm-up on the step mill at a rate of 45 steps per minute. They then rested passively for 3 minutes prior to blood pressure assessment. The test administrator then placed an additional 25 pound weight vest on the subject's shoulders, for a combined weight of 75 pounds. The test began with an additional 30 second warm-up at 45 steps per minute. After 30 seconds, the administrator began the test by increasing the step rate to 60 steps per minute, where it remained for 3 minutes. Heart rate was recorded as the step mill increased to 60 steps per minute and was recorded every 30 seconds thereafter. Automatic blood pressures were taken at 1, 2, and 3 minutes into the testing protocol. Following the 3 minute test, subjects dismounted and the weight vests were removed. The stair-climb was performed with the same parameters as the stair-climb portion of CPAT.

Candidate Physical Abilities Test (CPAT): The CPAT is a medley of firefighting specific tasks performed while wearing a 50 pound load simulating the Self-Contained Breathing Apparatus (SCBA) designed to simulate the conditions a firefighter may face in an emergency situation. CPAT consists of 8 tasks separated by a recovery interval of an 85 feet walk. Subjects were required to walk during this interval. They were timed for the duration of each task as well as during each transition using standardized procedures for all 8 tasks as described by the Fire Service Joint Labor Management Wellness/Fitness Initiative of the International Association of Fire Fighters (IAFF) and

International Association of Fire Chiefs (IAFC). The sum of each task and transition constituted the cumulative time, measured in seconds. A passing score is a cumulative performance time less than or equal to 10 minutes and 20 seconds. No testing was performed prior to CPAT or on the day prior to performing CPAT.

The first task was the stairmill climb. The subject wore an additional 25 pound weight vest. The subject warmed-up at a rate of 50 steps per minute for 20 seconds. At the end of the 20 second period, the test commenced and the subject climbed at a rate of 60 steps per minute for 3 minutes. The task was concluded upon dismounting the stairmill and the removal of the additional weight.

The second task (hose drag) consisted of dragging a 200 foot fire hose 75 feet, executing a 90 degree turn, then dragging the hose a further 25 feet. The subject then dropped to one knee and pulled in 50 feet of hose.

The third task (equipment carry) consisted of removing two saws from a shelf, one at a time, and placing them on the ground. The subject then picked up and carried the two saws for 75 feet, circled a drum, and returned to the starting point. The saws were placed on the ground, picked up one at a time, and placed back on the shelf.

For the fourth task (ladder raise and extension), the subject lifted the unhinged end of a 24 foot ladder and raised it in a hand-over-hand motion until it rested vertically on the wall. The subject then raised and lowered the fly section of a 24 foot ladder by pulling on a rope in a hand-over-hand motion. The task started when the subject made contact with the first ladder and ended with the release of the rope of the second ladder.

The fifth task (forcible entry) began when the subject picks up a sledgehammer. The subject swung the sledgehammer at a wall, depressing a metal box until the buzzer was activated. The task concluded when the subject released the sledgehammer after activating the buzzer.

The sixth task (search) consisted of crawling through a 3 feet high, 4 feet wide, and 64 feet long tunnel maze with 2 90-degree turns. Within the maze were obstacles. The task began when the subject placed a hand or knee on the ground while preparing to enter the maze. The task is completed upon returning to two feet after exiting the maze.

During the seventh task (rescue), the subject dragged a 135 pound mannequin by attached handles for 35 feet, executed a 180 degree turn around a drum, and returned 35 feet to the starting position. The task began when the subject first made contact with the mannequin and ended with the release of the mannequin after dragging the mannequin across the finishing line.

The eighth task (ceiling breach and pull) began when the subject stepped inside the metallic structure. The subject used a pike pole to raise a weighted, hinged door 3 times. The subject then used the pike pole to pull down on a second hinged door for 5 repetitions. This process is repeated 3 more times for a total of 4 rounds. The task concluded when the subject stepped outside of the structure.

Statistical Analysis: Means and standard deviations were calculated for all variables. Pearson product-moment correlation coefficients were calculated to determine correlations between the physiological attributes described above (independent variables) and CPAT performance (dependent variable). Correlations between these independent variables and rate-pressure product were also calculated in the same manner. To minimize the chances of a type 1 error due to multiple correlations, P values were set at 0.01 for all correlations.

The combination of physiological characteristics that best predicts CPAT performance was determined by linear regression analysis. Likewise, this analysis was used to determine the physiological attributes that best predict independent task performance. In order to determine the best regression model, all variables significantly correlated with the dependent variable (CPAT or individual CPAT tasks) were placed in a stepwise regression model. The resulting equation which predicted the largest portion of the variance was then selected.

When significant correlations were present for rate-pressure product relationships, linear regression was used to determine the most significant predictors. P values were set at 0.05 for these comparisons. To determine which variables were related to passing and failing the CPAT, subjects were separated into two groups, i.e., those who passed and those who failed the CPAT based upon the 10 minute and 20 second criteria set by the International Association of Firefighters (IAFF)/International Association of Fire Chiefs (IAFC). T-tests for two independent means were performed to determine significant differences between the two groups. To minimize the chances of a type 1 error due to multiple tests performed, P values for significance were set at 0.01 for this portion of the analysis.

Results

Subjects. Subject characteristics for men and women both combined and separated are presented in Table 1. Men were significantly taller (*P* = 0.001) and heavier (*P* = 0.003) than women, but there were no differences in percent body fat (*P* = 0.506).

Muscle Strength, Muscle Power, VO2max, and WAnT. Table 2 shows muscle strength, muscle power, VO_2max, and WAnT for men and women. As expected, men demonstrated significantly higher muscular strength in chest press ($P < 0.001$), leg press ($P < 0.001$), and knee extension ($P < 0.001$) exercises than women. Men also exhibited significantly higher peak power ($P < 0.001$) and mean power ($P < 0.001$) during WAnT. However, when standardized to body weight, there were no significant differences in VO_2max (*P* = 0.454) and peak power during WAnT (*P* = 0.101), while differences in mean power approached significance in favor of the men (*P* = 0.020).

Determinants of Successful CPAT Performance. Subjects were placed into two groups, those with passing CPAT times (n=18) and those with non-passing times (n=15). Completing CPAT in less than 10 minutes and 20 seconds is considered a passing performance by the IAFF. Mean values for each physiological variable were calculated by group. These means were compared using t-tests for independent means to determine which variables distinguished successful CPAT performers from non-successful performers.

Figure 1B depicts mean power during WAnT. Mean power during WAnT was 45% higher in those who completed CPAT with a passing score, as compared to those who did not ($P < 0.001$). In Figure 1A, mean power expressed relative to bodyweight was 25% higher in successful CPAT performers ($P < 0.001$). Moreover, Figure 1C shows that peak power per kg of body weight during WAnT was 22% higher in those who successfully completed CPAT ($P < 0.001$). Differences in peak power expressed in absolute terms during WAnT were right on the borderline for being significant ($P = 0.011$). Additionally, absolute VO_2max was 23% higher in firefighters who successfully completed CPAT ($P < 0.001$). When VO_2max was expressed relative to body weight, differences between groups were attenuated (17%), but still significant ($P < 0.01$).

Lower body strength was not significantly different between successful and non-successful CPAT performers. However, greater upper body strength in successful performers ($P = 0.038$) approached significance. Differences between groups also approached significance for percent body fat ($P = 0.029$), peak heart rate in response to stair climbing ($P = 0.015$), and percentage of maximal heart rate achieved during stair climbing ($P = 0.013$).

Relationship Between Physical Attributes and CPAT Performance Time. The relationships between each physical attribute (i.e., VO_2max, WAnT performance, muscle strength, muscle power, body composition, and cardiovascular response to stairclimbing) and CPAT performance time were assessed using Pearson correlation coefficients. The variable with the strongest relationship to CPAT performance was mean power during WAnT ($r = -0.66$; $P < 0.001$). This relationship remained significant when mean power was normalized for body mass ($P < 0.001$). In addition, fatigue index during WAnT ($r = 0.559$; $P < 0.001$) was significantly related to CPAT performance. Absolute VO_2max ($r = -0.602$; $P < 0.001$) and upper body strength ($r = -0.485$; $P < 0.001$) were also significantly related to CPAT performance. Furthermore, maximal heart rate response to stairclimbing was significantly related to performance time ($r = 0.523$; $P < 0.01$), and percent of maximal heart rate achieved during the stairclimb approached significance (r =

0.488; $P = 0.012$). In contrast, lower body strength ($P = 0.044$) and percent body fat ($P = 0.104$) were not significantly related to CPAT performance.

The results of the linear regression analysis determined that absolute VO_2max and fatigue index during WAnT combined best predicted CPAT performance time (Adj. $R^2 = 0.817$; $P<0.001$). Their combined predictive power was higher than their individual contributions.

Relationship between physical attributes and successful CPAT performance. In a separate analysis, Spearman correlation coefficients were used to determine the relationships between each physical attribute (VO_2max, WAnT performance, muscle strength, muscle power, body composition, and cardiovascular response to stairclimbing) and successful CPAT performance. These results are presented in table 4. Absolute mean power during WAnT ($r = -0.66$; $P < 0.001$) demonstrated the strongest relationship with successful CPAT performance, such that individuals with high WAnT performance were more likely to complete CPAT with a passing score. Significant differences between groups (i.e., those who passed vs. those who failed CPAT) remained when mean power was normalized for body mass ($P < 0.001$). Both absolute peak power ($r = -0.548$; $P < 0.01$) and relative peak power ($r = -0.548$; $P < 0.01$) during WAnT were significantly related to successful CPAT performance. Absolute VO_2max was also highly related to successful CPAT completion ($r = -0.620$; $P < 0.001$).

In contrast to our hypothesis, however, upper body strength ($P = 0.046$), lower body strength ($P = 0.021$), and percent body fat ($P = 0.0250$) approached, but did not reach significance for being related to successfully completing CPAT. CPAT performance and heart rate response to stairclimbing, both in absolute terms ($P = 0.012$), and when expressed as a percent of maximal heart rate ($P = 0.017$) approached significance.

Determinants of rate-pressure product (RPP). Neither VO_2max ($P = 0.378$), body composition ($P = 0.340$), nor lower body strength ($P = 0.940$), were significantly related to RPP.

Individual task determinants. Linear regression was used to determine which combination of physical attributes best predicted individual task performance time, linear regression was performed. Separate models were constructed for each of the individual CPAT tasks and results are presented in Table 5. Because not all subjects performed all aspects of testing, some regression equations contain less than 33 subjects. All models were significant ($P < 0.05$) with the exception of the model for ceiling breach and pull. The R^2 values ranged from 0.25 to 0.73. Similar to the findings with regression models for total CPAT time, measures of cardiovascular and anaerobic fitness were the best predictors of individual task performance. The combination of mean power during WAnT and heart rate at the conclusion of the stairclimbing task best predicted performance time during the hose drag ($R^2 = 0.61$; $P = 0.0001$). Performance during the ladder raise and extension was related primarily to mean power during WAnT and the percentage of maximum heart rate achieved during stairclimbing ($R^2 = 0.68$; $P < 0.0001$). Forcible entry performance was best associated with the combination of sex and mean power during WAnT ($R^2 = 0.73$; $P < 0.0001$). The combination of mean power during WAnT, height and diastolic blood pressure at the conclusion of stairclimbing best predicted performance during the search tasks ($R^2 = 0.65$; $P = 0.0002$). The remaining models are shown in table 5.

Discussion

The results of this study describe, for the first time, the relative contributions of anaerobic fitness, maximal oxygen uptake, muscular strength, percent body fat, and the cardiovascular responses during stairclimbing to CPAT performance. It is also the first report to assess the physiological determinants of individual tasks during the CPAT. The data indicated that the influence of VO_2max, expressed in absolute terms, and anaerobic fatigue resistance combined significantly predict a substantial portion of the variance (82%) in CPAT performance. This finding complements and extends the recent work by Williams-Bell et al. (92) who observed oxygen uptake (VO_2) values in excess of 38 ml/kg/min, heart rate (HR) > 165 beats per minute (bpm), and respiratory-exchange ratio > 1.0 for individual firefighting tasks, indicating high levels of both aerobic and anaerobic metabolism. However, the hypothesis that anaerobic fitness would serve as a strong predictor of firefighting performance was only partially supported by the results. For example, although upper body strength was a significant predictor of CPAT performance, neither upper nor lower body strength met the criterion ($P < 0.01$) for being a significant predictor of CPAT success (pass versus fail). The specific hypothesis that anaerobic fitness would serve as a better predictor of performance than aerobic capacity was not supported by the data. Regression equations describing the physiological attributes as determinants of individual CPAT tasks were significant for all tasks, except the ceiling breach and pull. However, no relationship was observed between rate-pressure product (RPP) during stairclimbing and any of the assessed physical attributes.

The finding that absolute VO_2max is significantly related to firefighting performance was supported by von Heimburg et al. (89), who found that absolute, and not VO_2max relative to body mass, was the best predictor of firefighting tasks. Additionally, absolute VO_2max was recently shown to be the best predictor of CPAT performance (92). These findings suggest the importance of possessing a large metabolic capacity, independent of body size (10). Prior research has demonstrated oxygen uptakes approaching or in excess of 40 ml/kg/min during simulated firefighting tasks, indicating a high oxygen requirement during firefighting (9, 10, 34, 43, 60, 92). A large absolute VO_2max may allow the firefighter to meet these energy demands without significant activation of anaerobic metabolic pathways, thereby preventing or delaying fatigue. While the relationship between absolute VO_2max and CPAT performance could indicate the importance of body size to performance, body mass was not found to be related to performance in the present study.

Because anaerobic metabolism contributes ~ 30-40% of energy demands during simulated firefighting tasks (10), as well as the associated elevated lactate levels (34, 63, 75, 89), it was hypothesized that there would be significant anaerobic contributions to the CPAT. There are only prior two reports on this relationship (65, 92), with only one using the CPAT as a surrogate to firefighting performance (92). Rhea et al. (65) concluded that 400-meter run time was significantly related to overall firefighting task performance time ($r = 0.79$) and Williams-Bell et al. (92) did not report the relationship between anaerobic capacity and CPAT performance. However, no differences were found in anaerobic fatigue resistance between individuals who completed CPAT and those unable to complete CPAT (92).

The discrepancy between the findings of the current study and those of Williams-Bell et al. (92) may be explained by differences in methodology and purpose. The present study utilized active professional and volunteer firefighters to focus on the extent to which their physiological attributes predicted their CPAT performance, whereas, Williams-Bell et al. (11) used volunteers with no prior firefighting experience to focus on the physiological demands of the CPAT. The intent was to minimize the influence of skill acquisition as a potential confounding variable by using firefighters familiar with all the tasks comprised in the CPAT. We also attempted to control for fatigue effects by separating tests that could impair performance on subsequent tests. VO_2max, muscular strength and endurance testing preceded the Wingate test (WAnT) during the single day testing battery in the study by Williams-Bell et al. (11), which could have influenced WAnT performance and the relationship between WAnT performance and CPAT performance.

The finding that anaerobic fatigue resistance and absolute VO_2max combined best predicted CPAT and contributes to such a large portion of the total variance in CPAT performance (82%) is novel. While absolute VO_2max has previously been shown to be independently related to CPAT performance, CPAT's relationship to anaerobic fatigue resistance has been less clear (92). However, both oxygen-dependent (9, 10, 34, 43, 60) and oxygen-independent systems (10, 34, 63, 75, 89) appear to be activated during firefighting tasks and these metabolic systems are thought to be the best independent predictors of firefighting performance (65, 89, 93).

Lower body strength was not significantly different between successful and non-successful CPAT performers in the present study, although a trend towards a significant difference was evident. Predicted leg press strength has recently been shown to be related to CPAT performance (92). In contrast, Rhea et al. (65) and von Heimburg et al. (89) found no relationship between quadriceps strength and firefighting performance. Predicted muscular strength (92), but not true muscular strength (65, 89) may be related to firefighting performance, these findings may be explained through differences in methodology. It appears that metabolic endurance is more critical to firefighting performance than lower-body strength, and a repetition-based strength test could inflate strength values of those possessing greater endurance.

The observation that upper body muscular strength was significantly related to CPAT performance time is supported by previous research showing that bench press (65, 89) and pull-up (93) performance were significantly related to firefighting performance. More recently, bench press performance was also found to be positively correlated with CPAT performance (92). Others demonstrated a significant positive relationship between grip strength and firefighting performance (16, 65, 92, 93). Additionally, a strength index composed of leg, neck, and chest press was found to be higher in faster performers during a simulated firefighting rescue (89).

Percent body fat was not significantly related to CPAT performance, although trends towards significance were evident in the present study. These findings were supported by some investigators (26), but not by others (16, 93). The findings in the present study, and those of Rhea et al. (65), used more direct assessments of body composition, i.e., dual energy x-ray absorptiometry (DEXA) and air plethysmography, respectively. The studies that established a relationship between percent body fat and performance employed skinfold measurements (16, 93), which are associated with greater measurement error (94). These discrepancies may account for the conflicting findings.

The maximal heart rate response to a stairclimbing task was significantly and negatively related to CPAT performance in the present study. This finding may represent the advantage of starting the remainder of the CPAT at a lower percent of a person's true maximal heart rate. A greater HR response to stairclimbing may also indicate greater levels of cardiovascular activation during a standardized task, and thus a lower fitness level. RPP response to stairclimbing was not significantly related to CPAT performance, suggesting that myocardial oxygen consumption during this task is not related to overall CPAT performance. Contrary to the hypothesis, the rate-pressure response to a stairclimbing task was not significantly related to any measured physiological attributes.

The heart rate response to exercise can be influenced by many different factors in addition to the training status of the participant. These include, but are not limited to, caffeine usage (36), medications (31), and shift work. Because many of the subjects in the present study were shift workers, the latter may be especially important, as shift work has been shown to affect both blood pressure and heart rate dynamics (84). For these reasons, future investigations should address the relationship of shift work, heart rate variability, and the extent to which shift work influences occupational stress.

While the cardiovascular and metabolic response to individual tasks during CPAT has been investigated (92), this study is the first report on the physiological determinants of individual tasks during CPAT performance. The results of regression analyses determined significant prediction equations for all individual tasks except the ceiling breach and pull in the current study.

Similar to the finding that anaerobic resistance to fatigue and absolute VO_2max best predict total CPAT performance, measures of aerobic and anaerobic fitness best predicted individual task performance. For example, measures of anaerobic fitness were related to hose drag, ladder raise and extension, forcible entry, and search tasks. Additionally, sex and the cardiovascular response to stairclimbing were significant predictors of task performance. Explanations for these relationships are beyond the scope of this study, but examples of tenable speculations are as follows. Because forcible entry requires a sustained high force and metabolic output, it is logical that anaerobic capacity would be related to performance. As the ladder must be moved quite rapidly, this may account for the importance of anaerobic capacity to task performance. Individuals with greater anaerobic fitness may be able to continue to function at a high level during the search, while less fit individuals are required to use this period to recover from prior exertion.

Measures of aerobic fitness were related to rescue and equipment carry. As the rescue task requires significant metabolic output, and is located at the end of the medley, an elevated absolute VO_2max may reduce accumulated fatigue prior to the rescue task, as well as allow for greater metabolic output. As equipment carry is a submaximal task, those with greater aerobic fitness perform submaximal tasks with less disruption to metabolic homeostasis because of greater reserve capacity, resulting in greater speed.

The CV response to stairclimbing was related to hose drag, equipment carry, ladder raise and extension, and search tasks. As the hose drag and equipment carry task is performed immediately following the stairmill, it would make sense that a reduced heart rate following the stairmill would be advantageous during these tasks. However, it is not immediately clear why the CV response to stairclimbing would significantly predict ladder raise and extension or search performance, which are performed later during CPAT.

Sex significantly predicted performance during forcible entry and rescue. These tasks require the firefighter to overcome significant resistance for a prolonged period of time. As men were found to be significantly stronger, more powerful and possess greater anaerobic fitness than women in the present study, these differences may account for the importance of sex during forcible entry and rescue. Previous research has shown strength (93) and anaerobic endurance (65) to be significantly related to victim drag performance.

There were several limitations in the present study. The relatively small sample size of non-randomly selected subjects may have limited the scope of the population for which the results can be generalized. Additionally, the low number of female participants limited our ability to make accurate and reliable determinations of sex differences in our results. Future investigations should study larger groups of women to confirm whether the physiological attributes in this study tend to influence CPAT performance differently in women. Lastly, due to the cross-sectional design of the present study, we are unable to determine causal or independent relationships between specific physical attributes and CPAT performance. Future research should seek to establish independent effects by using interventions, such as exercise training programs and control groups to isolate changes in independent physiological attributes and to control for other intervening factors that could influence CPAT performance.

In conclusion, the combined influence of anaerobic and aerobic capacity best predicts CPAT performance, in addition to performance time in individual tasks. Improving aerobic capacity and anaerobic fatigue resistance should be a major focus of remedial programs designed to improve firefighting performance.

Review of Literature

The firefighting occupation is characterized by regular and significant physical exertion. As such, it is important to identify the physiological responses to the working environment, as well as the relevant physical fitness requirements of the occupation.

Discrepancies between requirements and abilities can lead to an inability to adequately satisfy job performance requirements, as well as magnify the risk for cardiovascular events, a risk already exaggerated by the nature of fire suppression activities. It is also important to identify the link between the physical fitness and job performance by determining which aspects of fitness are most critical to success. Finally, having identified the attributes relevant to successful job performance, it becomes necessary to identify the efficacy of various training interventions at improving these fitness markers, and ultimately, firefighting performance. To provide background information relevant to all these areas this review will focus on 1) cardiovascular disease in firefighters, 2) occupational risk factors, 3) physiological responses to firefighting (cardiovascular, metabolic, and endocrine responses), 4) fitness characteristics of firefighters, 5) fitness and job performance, and 6) needs for future research.

Cardiovascular Disease in Firefighters

Epidemiological studies examining cardiovascular mortality rates among firefighters, as compared to the general population, have yielded inconsistent results. Firefighters are consistently exposed to byproducts of combustion reactions which may amplify the effect of risk factors for cardiovascular disease. Specifically, carbon monoxide (CO), which preferentially binds to hemoglobin, is present in high levels during fires, serving to depress oxygen delivery at the cellular level. Consistent CO exposure has been linked to an elevated cardiovascular mortality risk (82). Cyanide is a second compound elevated during fire suppression with potentially negative cardiovascular effects. Approximately 10% of Boston firefighters received significant cyanide exposure (86). Furthermore, Kales et al. has reported that a significant number of hazardous materials firefighters were hypertensive (47).

Because of these risk factors, numerous long-term studies have sought to examine the effects of firefighting on cardiovascular-related mortality. Amongst 5655 Boston firefighters followed from 1915 through 1975, firefighters were found to have a standardized mortality ratio (SMR) of 86 for cardiovascular-related death, with 100 implying equal risk as compared to mortality rates among Massachusetts males (59). 830 Parisian firefighters demonstrated a non-significantly decreased risk ratio (.74) of ischemic heart disease mortality over a 14-year period (21). Furthermore, Stockholm firefighters have been shown to be at lower relative risk for circulatory disease (85).

Similarly, a study examining mortality rates in 34,796 male and 2,017 female Floridian firefighters found that male firefighters did not have a significantly greater risk of dying from cardiovascular disease, and in fact, demonstrated a reduced risk of cardiovascular death, as well as death from diabetes or respiratory disease. In this context , no evidence of increased cardiovascular risk has been found by several research investigations (7, 20, 24, 40, 68).

In contrast, cardiovascular SMR among 886 Danish firefighters over a 10 year period was non-significantly increased (SMR=115). However, SMR was significantly elevated in males aged 40-59 during the first 5 years of the 10 year study period (SMR=177) (41). Female firefighters have also been shown to exhibit a nearly 4-fold increase in cardiovascular death rate (54).

Among Hawaiian firefighters there was a small, but non-significant elevation in cardiovascular mortality risk ratio (1.16), as compared to mortality rates of Hawaiian males within the same time period (38). Seattle firefighters who actively served for more than 30 years had a risk ratio of 1.84 as compared to firefighters who had only served for

15 years or less (42). Aronson et al. established an elevated risk of aortic aneurysm among Toronto firefighters (2), while Bates et al. found a significantly elevated SMR for CHD among the same population (6). Finally, Philadelphian firefighters over an 80 year period had a slight, but statistically significant (SMR=1.09) increase in the incidence of ischemic heart disease (4).

In a prospective study examining the prevalence of coronary heart disease (CHD) among firefighters, 806 male Cincinnati firefighters were followed for an average of 6.4 years (35). Firefighters aged 30-39 had a non-significant decrease in myocardial infarction (MI) rate as compared to a control group. The individuals who developed CHD smoked more often, were older, and were characterized by a family history of CHD, high blood pressure, and worse blood lipid profiles. However, the incidence of smoke inhalation and the firefighting occupation were not significantly related to incidence of CHD.

While the overall cardiovascular mortality rate among firefighters is somewhat ambiguous, when these events occur is less so. It has been demonstrated that the incidence of death from CHD among firefighters was significantly higher during fire suppression, alarm response, return from alarm response, and physical training (48). Emergency duties appear to be associated with higher incidence of CHD-related death, where as non-emergency duties do not. The rate of death was 10 to 100 times higher during fire suppression. Fighting fires leads to a significant activation of the cardiovascular (74, 75) and sympathetic nervous systems (64), and this activation may account in part for the higher incidence of cardiovascular events during fire suppression.

The above findings indicate that the risk of cardiovascular disease among the firefighting population has not been clearly established. Research has consistently shown that there is not necessarily an increased risk for CHD among firefighters, or only a minimal increase in risk (69). One of the limiting factors in mortality outcome research in firefighters is that of the healthy work effect.

The majority of mortality studies have demonstrated that firefighters have a decreased of all-cause mortality as compared to the general population (2, 4, 7, 19, 21, 24, 40-42, 59, 85, 87). The healthy worker effect posits that there is a selection bias towards firefighters, in that healthier individuals are more likely to apply for and be accepted into firefighting employment. This phenomenon may hide adverse effects on cardiovascular disease associated with the occupation (90).

The healthy worker effect may be present among firefighters for several reasons. The physical nature of firefighting may provide health benefits due to physical activity not found in other occupations. Furthermore, the selection process may be inherently biased towards healthier applicants. 24.7% of Cincinnati fire service applicants were denied due to health concerns (35). Because cardiovascular disease is a chronic disease, and numerous risk factors have been identified, susceptible individuals may be screened out during the hiring process. Furthermore, diabetes is a strong risk factor for cardiovascular disease, as well as a criterion for exclusion from the fire service. Additionally, those who begin to experience significant symptoms of cardiovascular disease would be unable to complete their occupational requirements, and may leave the fire service prior to experiencing a mortal event. Thus, a significant healthy worker effect may be present in firefighter mortality research.

Choi reassessed 23 cardiovascular mortality studies in firefighters by taking the healthy worker effect in to consideration (14). Prior to re-assessment, 7 of 23 studies showed a link between firefighting and cardiovascular disease. After re-assessment, 4 additional studies demonstrated a link between firefighting and cardiovascular disease. Choi concluded that there is significant evidence for an increased risk of death from cardiovascular disease among firefighters, but no elevated risk of aortic aneurysm.

While the evidence is not conclusive, it appears that a significant number of mortality studies have demonstrated an increased risk of cardiovascular-related mortality among firefighters; particularly after the healthy worker effect has been considered. Thus, it appears that intervention, possibly in the form of physical activity, may be warranted or necessary, in order to reduce the risk of cardiovascular disease-related death among firefighters.

Occupational Risk Factors

In addition to potentially elevated risk of cardiovascular disease-related death, many studies have reported an elevated risk of several types of cancer among the firefighting population (7, 21, 38, 40, 41, 54). The most common forms of cancer identified include thyroid cancer, breast, brain, prostate, esophageal, and lung cancer.

Additionally, due to the physically demanding and fatiguing nature of firefighting, firefighters may be at greater risk for musculoskeletal injury. Gregory et al. examined the effects of fatigue on posture and trunk muscle activation (37). During the course of a Candidate Physical Ability Test (CPAT), there was a significant decrease in abdominal muscle activation, coupled with an increase in spinal flexion. These alterations may predispose firefighters to lower back injury.

Physiological Responses to Fighting Fires

The physiological responses to simulated firefighting tasks have been extensively characterized. Much of the literature has focused on cardiovascular and metabolic responses to actual and simulated firefighting activities. Traditionally, aerobic metabolic responses have been emphasized at the expense of anaerobic responses. The hormonal responses to firefighting in a simulated live-fire situation have also been briefly investigated.

Cardiovascular Responses. The heart rate (HR) response to firefighting activities has been consistently reported. During live-fire drills in full gear, heart rate increased over time to a maximum rate of 183 beats per min (bpm) (75). Similar results were reported in a separate study by the same researchers, with HR peaking at 189 bpm (74). During a simulated rescue, HR was elevated to 182 bpm, corresponding to 96% of max (89). Mean HR was 90 % of maximum during the Candidate Physical Ability Test (CPAT), a firefighting entrance examination (92). Firefighting tasks conducted at the Kennedy Space Center elicited heart rates equivalent to 93-97% HR_{max} (72). Other studies have reported similar results, with HR reaching 186 bpm (8), 176 bpm (78), 90-100% of HR_{max} (55), 97% of HR_{max} (12), and 180 bpm (95% of HR_{max}) (53). Additionally, firefighters responding to an emergency call exhibited a mean HR of 157 for 15 minutes, which was equivalent to 88% of the previously determined HR_{max} (81).

In actual emergency conditions, one firefighter was reported to have a mean HR of 188 bpm for 15 minutes (5). Mean heart rate has also been shown to be 182 bpm during 8 minutes of advancing a fire hose (77). It has also been shown that stair-climbing tasks in full gear elicit 95% of maximum heart rate (60). Clearly, there is a significant activation of the cardiovascular system during firefighting tasks. Heart rates have been consistently been shown to approach maximal levels, indicating a significant energy demand. As such, fighting fires has been shown to result in significant energy expenditure and cardiovascular response (12).

The HR response has also been characterized by variation over the course of simulated drills and live-fire situations, with HR often varying as function of the specific task being performed. Romet et al. reported that HR varied from 122 to 153 bpm during 6 different firefighting scenarios, with less physically demanding tasks demonstrating lowered HR responses (67). Tasks such as drum carry (DC) elicited heart rates of 170 bpm, while boundary cooling (BC) elicited a HR of 149 bpm (10). During smoke-diving, peak HR was 180 bpm while mean HR was 150 bpm, implying variance of HR during activity (53). Finally, in firefighter instructors during drills, average HR was 109 bpm and maximum HR was 138 bpm, equivalent to 90% of heart rate reserve (23). The variation in HR over the course of firefighting activity, as demonstrated by the data above, implies that firefighting is not a steady-state activity.

In two separate studies, Smith et al. (74, 75)characterized stroke volume (SV) and cardiac output (Q) over the course of live-fire training drills. In the first study, SV decreased over time from 89.6 ml/beat prior to exercise to 62.3 ml/beat at the conclusion of the training drills in one type of training gear and from 85.1 ml/beat to 59.9 ml/beat in another. In the second study, SV increased from 78.3 ml/beat at rest to 97.9 ml/beat, then dropped to 63.4 ml/beat by the conclusion of the drills (74). Zhou et al. demonstrated that SV in sedentary males can decrease with escalating exercise intensity (95). This study, coupled with the above data in firefighters, may imply that many firefighters do not possess optimal fitness levels. Similar to SV, in both studies Q rose from baseline during drilling and then fell, in spite of increasing heart rates. In the first study, Q rose from 6.9 L/min to 14.2 L/min, and then progressively fell to 11.4 L/min. Within the same study, firefighters wearing a different type of training gear exhibited similar responses with Q rising from 6.7 L/min to 15.1 L/min, then falling to 10.8 L/min (75). The cardiac output of firefighters in the second study rose from 8.1 L/min to 17.1 L/min, and then fell to 12.0 L/min (74). The above data suggests that the inability to maintain cardiac output and supply peripheral tissues with adequate blood flow and oxygen may be a limiting factor in firefighting performance.

The cardiovascular responses to firefighting tasks are both significant and variable in nature. High heart rates imply a large demand on the firefighter's cardiovascular system. However, this demand may not be uniform, as evidenced by the variation in HR response over time and across different tasks. Additionally, the drop in SV over the course of simulated fire rescues may imply that many firefighters do not possess the physical fitness to adequately match the demands of the job (95). The drop in cardiac output over time, in spite of near maximal heart rate responses, provides further evidence that the cardiovascular system is unable to match the demands of firefighting activity.

Metabolic Responses. The most often characterized metabolic response to firefighting activity is activation of the oxidative system, as measured by the volume of oxygen uptake (VO_2). It has been suggested that maximal oxygen uptake (VO_2max) is an important predictor of the ability to adequately perform firefighting tasks (80, 92). Several studies have also measured the level of lactate accumulation in the blood, which can indicate the degree to which anaerobic metabolism is activated. Finally, the relative contribution of aerobic and anaerobic metabolism in different firefighting specific task has been investigated.

The aerobic response to firefighting activity has been well established. During a simulated rescue, VO_2 in firefighters climbed to 44 mL/kg/min, representing 83% of VO_2max (89). Oxygen uptake during CPAT also exceeded 40 mL/kg/min (92). During smoke-diving tasks, VO_2 was 2.4 L/min, or 60% of aerobic capacity (53). In a simulated fire suppression, 73% of VO_2max was achieved (78). The same authors reported that VO_2 reached 25.6 mL/kg/min (63% of VO_2max) during an actual firefighting emergency (81). Lemon et al determined the oxygen uptake of firefighters during firefighting tasks to be 3.0 L/min (52). It has been shown that an oxygen consumption rate of 38 ml/min/kg must be maintained for 20-30 minutes among Royal Navy firefighters, leading the authors to recommend a VO_2max of 41 ml/kg/min as a minimum standard for firefighters (9). Stair-climbing tasks have been shown to elicit 80% of VO_2max and a minimal standard of 39 ml/kg/min was suggested (60).

Similar to heart rate dynamics, oxygen uptake has been shown to vary among different firefighting tasks. Gledhill et al demonstrated that the most demanding firefighting operations elicited an oxygen uptake of 41.5 mL/kg/min, while mean uptake was 23 ml/kg/min. These uptakes corresponded to 50 and 85% of VO_2max, leading the authors to recommend a VO_2max of 45 mL/kg/min as a minimum standard for applicants (34). In a separate study, oxygen uptake varied among different firefighting tasks, with drum carry (DC) eliciting a VO2 of 43 mL/min/kg and boundary cooling (BC) eliciting a VO_2 of 23 mL/kg/min (10). These oxygen uptakes represented 82 and 44% of VO_2max, respectively. Finally, Holmer et al. found that mean VO_2 consumption was 33.9 L/min, while peak VO_2 was 43.8 mL/kg/min (43).

In females, VO_2 values of 24 and 42 mL/kg/min were achieved for BC and DC respectively, corresponding to 55 and 98% of VO_2max. The absolute oxygen demand appears to be similar across sex, but females are typically working at higher percentage of their maximal uptake (10). The variation in oxygen demand across different tasks implies a non-steady state metabolic environment during firefighting activities.

Several studies have investigated the blood lactate response to exercise. Gledhill et al. showed peak lactate values of 6-13.2 mM/L (34). Additionally, von Heimburg et al. found blood lactate concentrations of 13.3 mM/L at the conclusion of a simulated fire rescue operation (89), while Smith et al. demonstrated blood lactate values of 4.2 mMol/L (75). Petersen et al. reported the highest lactate values recorded, with blood lactate reaching 15.57 mMol/L (63). Elevated blood lactate levels imply contributions of anaerobic metabolic processes to energy demand. Furthermore, it has been reported that firefighting tasks achieved heart rates in excess of heart rate at ventilatory threshold determined during a graded exercise test (63). This further supports the activation of anaerobic metabolism during firefighting tasks.

In a study by Bilzon et al., the authors characterized the relative contributions of aerobic and anaerobic energy processes during simulated firefighting tasks (10). The authors determined the relative energy demands through the use of respiratory gas exchange during firefighting tasks. Total metabolic demand (TMD) was characterized by the area under the VO2-time curve for the exercise period and a 10 minute recovery period. Total aerobic demand (TAD) was defined as the area under the VO2-time curve for the exercise period only. Total anaerobic demand (TAnD) was defined by the difference between TMD and TAD. Across different firefighting tasks as well as sex, the relative contribution of aerobic and anaerobic energy supply was relatively consistent. Aerobic energy contribution ranged from 60-66% and anaerobic energy contribution ranged from 34-40%. Respiratory-exchanges ratios (RER) in excess of 1.0 during CPAT also imply significant activation of anaerobic metabolism (92).

The response of aerobic metabolism to firefighting has been investigated in several studies with similar results. Fighting fires elicits a large oxygen uptake, both in absolute terms and when expressed as a percentage of an individual's VO2max. Several studies have reported oxygen uptakes in excess of 40 mL/kg/min (10, 34, 43, 89, 92). The anaerobic response to firefighting has been less thoroughly characterized, but two studies have demonstrated significantly elevated blood lactate concentrations (34, 63, 89), implying an anaerobic contribution to firefighting tasks. This was conclusively demonstrated by Bilzon et al., where the authors showed an approximately 60%-40% contribution of the aerobic and anaerobic energy systems, respectively (10).

Endocrine Responses. One study has investigated the hypothalamic-pituitary-adrenal axis response to live-fire firefighting drills (76). Adrenocorticotropic Hormone (ACTH) was found to be elevated by 400% immediately following the exercise period, but levels had returned to baseline after 90 minutes of recovery. Cortisol levels in the blood increased by 133%, but in contrast to ACTH, cortisol remained elevated when measured 90 minutes after the cessation of exercise. Elevated glucocorticoid concentrations are in line with the increased metabolic demand associated with firefighting activities.

In addition to elevations in blood cortisol, significant activation of the sympathoadrenal system has been demonstrated. Firefighters have been shown to exhibit a more than 2-fold increase in blood levels of the catecholamines, norepinephrine and epinephrine (64). Furthermore, individuals serving as firemen for 20-37 years, as compared to those serving only 10-19 years, had significantly elevated blood catecholamine levels.

Fitness Characteristics of Firefighters

Several studies have investigated the physical fitness characteristics of firefighters. Assessments of VO_2max have yielded varying results. Municipal (mean age =40.8) and industrial (mean age= 39.4) demonstrated VO_2max values of 47.6 and 48.6 ml/kg/min, respectively (33). Mean VO_2max values of 53.0 (89), 52.6 (10), 52.4 (53), 51.3 (73), 43.4 (76), and 39.60 mL/kg/min (16) have been reported. Research in female firefighters established mean VO_2max value of 43.0 (10). Anaerobic power and anaerobic capacity was not significantly different from a control group in female firefighters (30). In male firefighters, mean 400-m run time, a measure of anaerobic capacity, was 80.5 seconds (65). VO_2max has been suggested to be an important predictor of the potential effectiveness of a firefighter during firefighting specific tasks (80).

Differences in aerobic capacity across different studies can be explained to some extent by the testing methodology utilized. The differences include sub-maximal vs. maximal testing. In such studies, the latter employed metabolic testing where as the former estimated VO_2 through the relationship between work rate and heart rate. Additionally, the mode of exercise has not been consistent across investigations, with some studies using cycle ergometry and others using treadmill tests. It has been previously demonstrated that maximal aerobic capacity can differ across exercise modalities (15). Additionally, evaluating physical fitness through questionnaires has been shown to be an invalid form of measurement in firefighters (62).

Body weight in male firefighters ranged from 85.8-86.6 kg (29) and 85.1-87.1 kg (33). Mean bodyweight in female firefighters was 54.4-65.7 across different age groups (28). Firefighters in municipal and industrial departments demonstrated body compositions of 17.1% and 15.6%, respectively (33). Similarly, body composition values ranged from 17.2% to 19.8% in male firefighters in the 3rd to 5th decade of life (29). Varying body composition values of 13.78% (93), 16.6% (65), 16.7% (10), 16.9% (73), 17.7% (75), 18.1% (76), and 21.1% (16) have also been reported. Body composition values of female firefighters were 21.2%-26.9% across different age ranges (28). A second study in females yielded a mean body composition of 25.9% (10).

The differences in body composition, as well as body weight, to a large extent can explain the discrepancies between male and female firefighting performance (58). While there is some discrepancy among different studies, body composition appears to be relatively normal across the firefighting population. These inconsistencies could be a result of methodological differences.

In tests of performance fitness measurements, municipal firefighters were able to complete on average 42.4 sit-ups and 49.9 pushups. A sample of industrial firefighters completed a mean of 44.1 and 41.9 sit-ups and pushups, respectively (33). Similarly, Williford et al. reported mean sit-up and pushup values of 39.88 and 41.02, respectively (93). A study by Davis et al. yielded similar sit-up values (36.9), but much lower pushup values (19.0) (16). This discrepancy may be facilitated by differences in the technical execution of a push-up. Additionally, pushup and sit-up performance in male firefighters decreased from 37.3 to 32.0 and 62.8 to 50.6, repetitions respectively, from the 3rd to 5th decade of life (29). Mean pull-up scores of 9.03 (93) and 5.5 (16) have also been reported.

Total grip strength differed significantly between municipal (116.6±12.5 kg) and industrial (127.8±11.9 kg) firefighters. A second study recorded a total mean hand grip strength of 116.75 kg (93). Average single hand grip strength was 58.8 kg in one study (65) and 47.4 kg in another (16). Male firefighters in ages 20-29 demonstrated a mean 1-RM bench press of 92.5 kg. Male firefighters in ages 40-49 demonstrated a mean 1-RM bench press of 90.5 kg (29). The 1-RM bench press in female firefighters ages 20-29 was 30.1 kg in contrast to female firefighters ages 40-49 where 1-RM was 16.3 kg (28). Rhea et al. reported mean 5RM bench press and 5RM squat values of 217.6 and 298.0 pounds, respectively (65).

The effect of age on the fitness levels of firefighters has also been demonstrated. Negative correlations have been demonstrated between age and sit-up performance, as well as age and standing broad jump distance (49). Furthermore, one cross-sectional study demonstrated a non-significant decrease in aerobic capacity from the 3rd to 5th decade of life (33.0 mL/kg/min to 28.5 mL/kg/min) (29). A second cross-sectional study also demonstrated a non-significant decrease in aerobic capacity in female firefighters from the 3rd to 5th decade of life, with higher levels of fitness (37.0 to 35.0) (28). However, Saupe et al. demonstrated significant decreases in aerobic capacity, with VO_2max dropping from 47.7 ml/min/kg to 31.5 ml/min/kg amongst 20-25 year old and

40-45 year old firefighters, respectively (71). Body composition also increased during the same time period from 8.3% to 27.2% (71).

The cardiovascular and anthropometric physical fitness characteristics of firefighters have been thoroughly evaluated. However, strength measures, particularly lower body strength, and measures of anaerobic performance have not been thoroughly assessed, creating a gap in the literature.

Fitness and Job Performance

Several studies have attempted to correlate measures of physical fitness with performance in firefighting specific tasks. A study by Williford et al. found significant correlations between several fitness and anthropometric variables and firefighting tasks (93). Percent body fat, fat free mass, number of pull-ups, pushups, and sit-ups, 1.5 mile run time, grip strength, and height were all significantly correlated with total task time (($P \leq 0.01$). Total grip strength proved to be the best predictor of total task time, with higher levels of strength predicting lower task time. Grip strength was also the strongest predictor victim rescue, hose advance, and hoist. Fat-free mass was the second strongest predictor. In the forcible entry task, fat-free mass was the best predictor of performance. 1.5 mile run was the best predictor of stair mill climb time.

Rhea et al. undertook a similar study with slightly different performance variables (65). The strongest predictor of total performance time was 400-m run, a measure of anaerobic endurance. Overall fitness, bench press strength, hand grip strength, and muscular endurance in the row, bench press, shoulder press, bicep curl, and squat were significantly correlated with total task performance ($P \leq 0.05$). In contrast to the prior study, the researchers did not find a measure of cardiovascular fitness (12-minute run) to be significantly related to any of the task performances. Additionally, body fat percentage was also unrelated to performance. Hand grip strength was the best predictor of hose pull performance, bench press strength was the best predictor of equipment hoist, and 400-m time was the best predictor of stair climb and victim drag.

Von Heimburg et al. characterized the physiological responses of a 14 firefighters during a training course which simulated a hospital rescue (89). Baseline fitness and anthropometric characteristics were correlated to total performance time. The subjects were grouped into a slow and fast group based upon total performance time. During the trial, subjects in the fast group achieved a significantly higher percentage of their VO_2max (.87±0.06 vs. 79±.005). The fast group also had a significantly lower accumulated oxygen uptake (16.9±1.5 vs. 19.9±1.4), implying a lower reliance on anaerobic metabolism. Height, bench press 1-RM, and press behind the neck 1-RM were all significantly greater in the fast group as compared to the slow group.

Subjects with a greater absolute VO_2max were able to complete the performance trial in less time (89). VO_2max, in relative terms, was not significantly different between groups, but the faster group was able to achieve a significantly higher percentage of VO_2max during the simulated rescue. This finding is in accordance with Sothmann et al., who demonstrated an inverse relationship between the relative percentage of VO_2max and performance time during a simulated fire suppression task (78). These same authors suggest that VO_2max, in conjunction with firefighting specific tasks, is an important indicator of the potential effectiveness firefighting performance (79).

Davis et al. also compared baseline fitness and anthropometric characteristics with performance in firefighting tasks (16). The researchers found that grip strength, sit-ups, standing long jump, maximal heart rate, sub-maximal O_2 pulse, body composition, lean body weight, and final treadmill grade were predictors of performance. Additionally, Misner et al. found body fatness to be negatively correlated with all tasks requiring movement and fat free mass to be positively correlated with tasks requiring force application (58).

Williams-Bell et al. examined the relationship between physiological attributes and CPAT performance (92). They found that absolute VO_2max was the most significant predictor of performance. Women who were unable to complete CPAT were significantly weaker and displayed a lower peak power than those women who were able to complete CPAT. Muscular strength and endurance, as measured by leg press and chest press movements, were significantly correlated to CPAT performance, as was anaerobic power. These results indicate that while VO_2max is the best predictor of performance, anaerobic power and muscular strength are also significantly related to firefighting performance.

Fogleman et al. established variables that separate low fitness and high fitness refinery firefighters. Body composition, body weight, and push-up performance were found to be the most important variables in terms of predicting fitness (32). It is suggested that these variables can help to identify firefighters who possess an insufficient aerobic capacity. This is an important consideration, as VO2max has been correlated with performance time in fire suppression tasks (78).

Several different physical attributes were found to be correlated with victim rescue task among Royal Navy firefighters (9). Measures of lean body mass, fat mass, standing broad jump, 20 meter sprint, press-ups, sit-ups, and grip strength combined to significant predict task performance ($R = 0.89$, $P < 0.01$). Interestingly, measures of anaerobic power, 20 meter sprint and standing long jump, were also significant predictors of performance.

There appears to be no effect of race on firefighting performance, as no performance differences were demonstrated between whites, Hispanics, and blacks (57, 79). However, males exhibited superior performance as compared to females during firefighting tasks (39, 57, 58, 79). Significant decreases in fire suppression task performance have been shown to occur with age, as firefighters over the age of 50 performed tasks significantly slower than those firefighters less than 50 years of age (79).

Measurements of aerobic, anaerobic, and neuromuscular fitness have been found to be related to firefighting performance. However, measures of cardiovascular fitness have not been consistently shown to be significantly related to performance. Non-cardiovascular fitness measures, specifically 400-m run, grip strength, and body composition, have been shown to be the best predictors of performance. Traditional focus has been on measures of aerobic or cardiovascular fitness, but these variables may not be the best predictors of firefighting performance.

Needs for Future Research

Training interventions in firefighters are limited in number and have focused primarily on the improvement of aerobic capacity, 1-RM strength measures, lean body mass, and body composition. A 1 hour/day, 3 days/week, combining traditional cardiovascular and strength interventions yielded 28% improvements in VO2max, 24% improvements in muscular endurance as characterized by pushup performance, in addition to significant increases in flexibility, lean body mass, and decreased fat mass (66). However, muscular strength did not improve significantly.

A second study conducted in the UK Fire Service demonstrated significant increases in VO2max (11%), lean body mass (2.02 kg), and both grip and lifting strength (26). However, these improvements disappeared following an 18-month service period, implying that service was not a sufficient stimulus to maintain fitness gains. Additionally, an anaerobic power did not increase.

Prior training interventions in the firefighting population have yielded significant improvements in aerobic capacity, in addition to strength gains. However, no study has improved or addressed the importance of measures of anaerobic metabolism in firefighters.

A novel strength training approach has been shown to yield several benefits of significance to the firefighting population. Utilizing Keiser A-300 pneumatic resistance training machines allow the user to work against a near maximal workload over a large training volume. This type of training has been shown to yield significant increases in muscle size across all populations (70). Improvements in one repetition maximum (1-RM) strength was shown to significantly improve in the chest press, lat pull-down, knee extension, and leg press (51), exercises utilizing muscle groups critical to firefighting performance. Knee extension 1-RM was shown to significantly improve in another study as well (50). Additionally, peak knee extensor power has been shown to increase significantly following a similar strength training protocol (18). Finally, it has been shown that maximal isometric strength of the hip and knee extensors is correlated with peak power (3) and mean power (83) during the Wingate Anaerobic Cycling Test, a measure of anaerobic power and capacity. Thus a strength training program that elicits improvement in lower body strength may serve to improve measures of anaerobic performance.

The adaptations associated with the above training protocol have been shown to be related to firefighting performance. The importance of cardiovascular and aerobic fitness to firefighting performance has been outline above, and prior training protocols have addresses these adaptations. However, training protocols eliciting anaerobic adaptations that may be of equal importance to firefighting have not been investigated. Thus, investigating the impact of training protocols emphasizing strength and anaerobic fitness on firefighting performance is of importance.

Appendix A- Delimitations & Limitations

The following represent the delimitations, as well as the potential limitations of the present study.

Delimitations

- The subject pool will be delimited to approximately 35 individuals who are 45 years of age or younger and are active individuals as employees or volunteers in the fire service in the Baltimore, Montgomery, and Prince Georges counties of the state of Maryland, as well as Prince Williams and Fairfax Counties of the state of Virginia.
- Subject selection will be delimited to those individuals who possess no more than two risk factors for cardiovascular disease, as determined by the American College of Sports Medicine (ACSM). Subject selection will be delimited to those individuals characterized as low risk, as outlined by the ACSM (1).

Limitations

- The cross-sectional design of the study does not allow for causative relationships to be established.
- Study participants are volunteers and are not selected randomly from the population. As such, there may be selection biases that diminish the ability to generalize the results of the study to populations who do not conform to the sample population's characteristics.
- The relatively small sample size limits the statistical power of the results.

Appendix B- Tables

The results of the present study are expressed in the following tables.

TABLE 1.Physical characteristics in men (N = 26) and women (N = 7) separated and combined (N = 33).

	Men	**Women**	**Combined**	***P***
Age (yr)	27 (7)	28 (6)	28 (6)	0.459
Height (cm)	181.7 (6.8)	169.9 (23.4)*	179.2 (9.0)	0.001
Weight (kg)	93.1 (20.5)	67.1 (9.8)*	87.6 (21.6)	0.003
BMI ($kg{\cdot}m^{-2}$)	28.1 (5.4)	23.3 (2.7)*	27.1 (5.3)	0.004
Percent Body Fat	21.9 (6.9)	23.7 (3.8)	22.2 (6.3)	0.506
VO_2 Max ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	40.9 (8.65)	43.6 (3.6)	41.5 (7.9)	0.454

Significantly different than men (P < 0.01)
Values are expressed as mean (SD)

TABLE 2. Physical characteristics in men (N = 26) and women (N = 7) separated and combined (N = 33).

	Men	**Women**	**Combined**	***P***
Chest Press 1-RM (Keiser units)	195 (38)	110 (16)*	177 (50)	<0.0001
Leg Press 1-RM (Keiser units)	727 (108)	459 (91)*	668 (153)	<0.0001
Knee Extension Left Leg 1-RM (Keiser units)	259 (43)	175 (54)*	240 (55)	0.0001
Knee Extension Right Leg 1-RM (Keiser units)	268 (48)	175 (44)*	247 (62)	<0.0001
WAnT Peak Power (watts)	841 (147)	563 (155)*	771 (191)	0.0002
WAnT Relative Peak Power (watts/kg)	9.4 (1.4)	8.3 (1.6)	9.1 (1.5)	0.1013
WAnT Total Work (watts)	16032 (2828)	10277 (2831)*	14482 (3802)	0.0001
WAnT Relative Total Work (watts)	182 (30)	150 (21)	173 (31)	0.0202
Knee Extension Right Leg Peak Power (watts)	852 (163)	500 (170)*	775 (219)	<0.0001
Knee Extension Left Leg Peak Power (watts)	814 (166)	488 (147)*	743 (211)	<0.0001
CPAT Time (seconds)	575 (82)	665 (100)	595 (92)	0.0314

Significantly different than men (P < 0.01)
Values are expressed as mean (SD)

TABLE 3. Correlations between physical attributes and CPAT time.

	R-value	**P-value**
Absolute VO2max	-0.60	0.0009
Chest Press 1-RM	-0.48	0.0089
Mean Power (WAnT)	-0.67	0.0005
Relative Mean Power (WAnT)	-0.60	0.0026
Total Work (WAnT)	-0.66	0.0005
Relative Total Work (WAnT)	-0.60	0.0026
Fatigue Index (WAnT)	0.56	0.0056
HR at Finish of Stairmill Task	0.52	0.0073
Diastolic BP at Finish of Stair Mill Task	0.51	0.0097

All results significant (P<0.01)

TABLE 4. Correlations between physical attributes and successful CPAT performance

	R-value	**P-value**
Absolute VO_2max	-0.62	0.0001
Ventilation	-0.49	0.0052

Peak Power (WAnT)	-0.55	0.0025
Relative Peak Power (WAnT)	-0.55	0.0026
Mean Power (WAnT)	-0.66	0.0002
Relative Mean Power (WAnT)	-0.60	0.0012
Total Work (WAnT)	-0.66	0.0002
Relative Total Work (WAnT)	-0.60	0.0012

All results significant ($P<0.01$)

Table 5. Regression coefficients for individual CPAT tasks.

	Estimate ± SE	R^2	*P* Value	
Hose Drag (N=22)		0.45	0.001	
Mean power during WAnT	0.051 ± 0.017 ***			0.0087
HR at conclusion of stairmill	0.418 ± 0.247 *			0.1068
Equipment Carry (N=27)		0.27	0.023	
Absolute VO_2max	-4.479 ± 2.348 *			0.0684
% of HR_{max} during stairclimb	33.877 ± 22.647 *			0.1447
Ladder Raise and Extension (N=23)		0.68	<0.0001	
Mean power during WAnT	-0.022 ± 0.006 ***			0.001
% of HR_{max} during stairclimb	36.577 ± 13.597 **			0.0141
Forcible Entry (N=25)		0.73	<0.0001	
Mean power during WAnT	-0.04 ± 0.012 ***			0.0037
Sex	9.742 ± 3.52 **			0.0112
Search (N=22)		0.65	0.0002	
Mean power during WAnT	-0.121 ± 0.027 ***			0.0003
DBP at conclusion of stairclimb	0.673 ± 0.264 **			0.02
Height	1.332 ± 0.37 ***			0.002
Rescue (N=28)		0.5	0.0002	
Absolute VO_2max	-16.319 ± 6.20 **			0.0143
Sex	18.54 ± 9.141 *			0.0533
Ceiling Breach and Pull		0.25	0.0501	
Absolute VO_2max	-18.943 ± 7.227 **			0.016
DBP at conclusion of stairclimb	-0.565 ± 0.386			0.158

VO_2max- maximum oxygen uptake; HR_{max}- maximum heart rate; WAnT- wingate anaerobic cycling test; DBP- diastolic blood pressure

* $P < 0.15$

** $P < 0.05$

*** $P < 0.01$

Appendix C- Figures

The results of the present study are expressed in the following graphs.

FIGURE 1A.

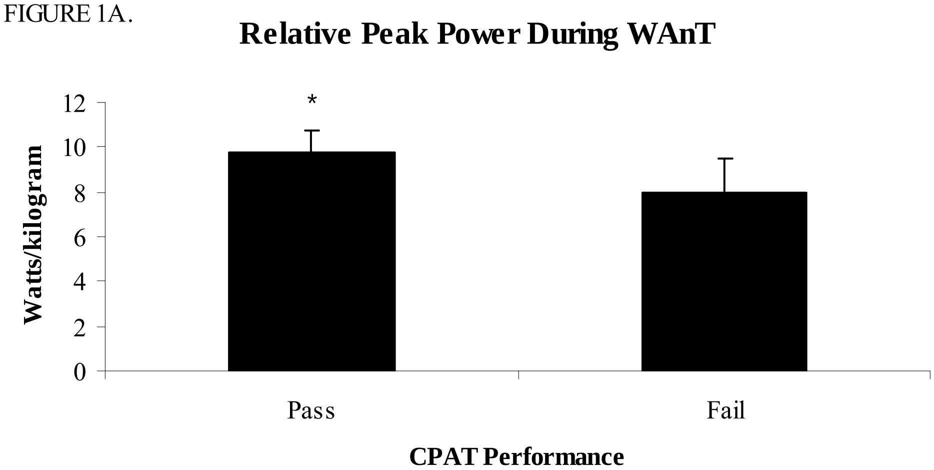

FIGURE 1B.

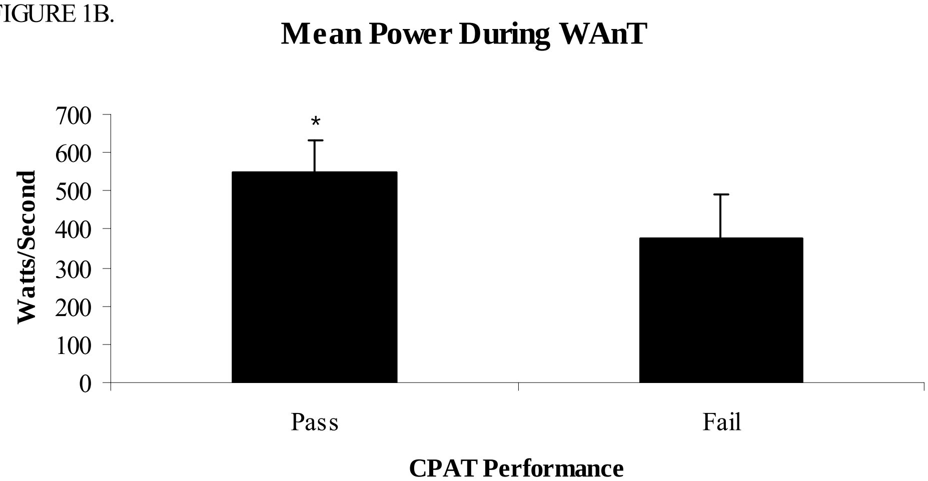

FIGURE 1C.

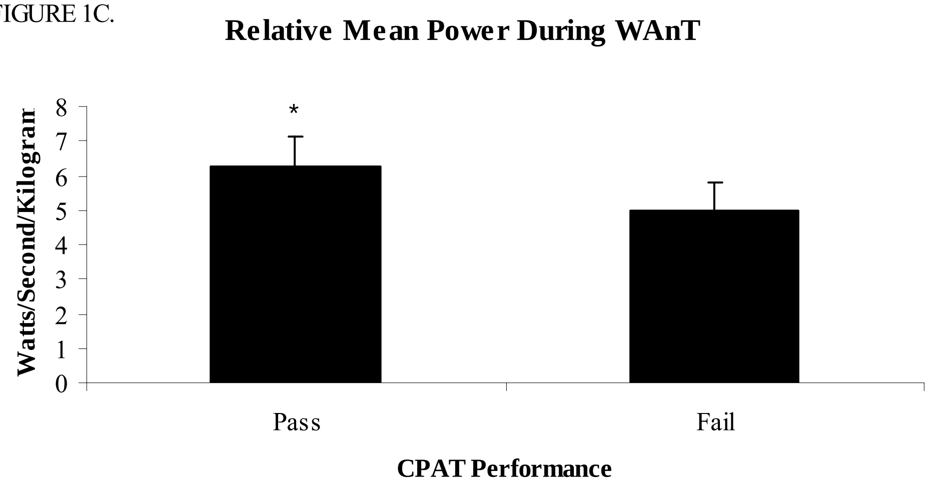

FIGURE 1- Relative peak power (watts/kg, A), mean power (watts/sec, B), and relative mean power (watts/kg/sec, C) during WAnT in those who pass (≤ 10 min & 20 sec) versus those who fail (> 10 min & 20 sec) the Candidates Physical Ability Test (CPAT). The asterisk (*) signifies values are significantly different than in those who fail the CPAT, ($P < 0.01$). Values are presented as mean ± SD.

FIGURE 2A.

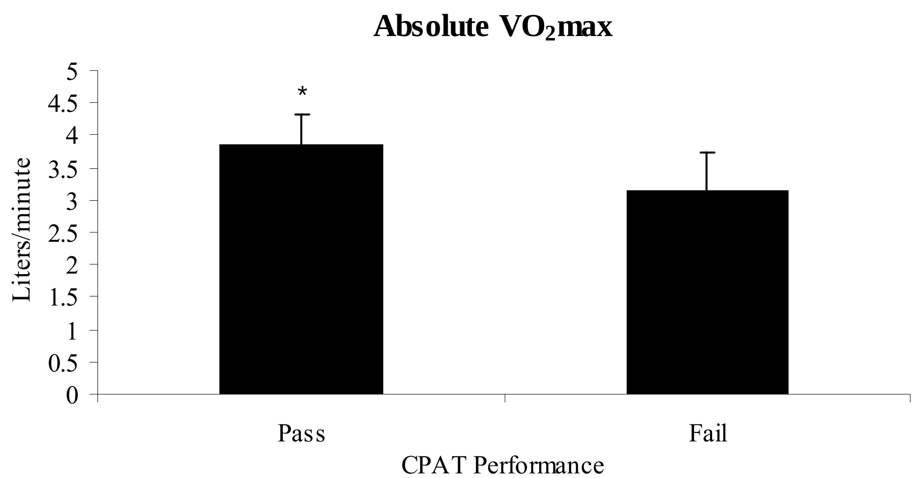

FIGURE 2B.

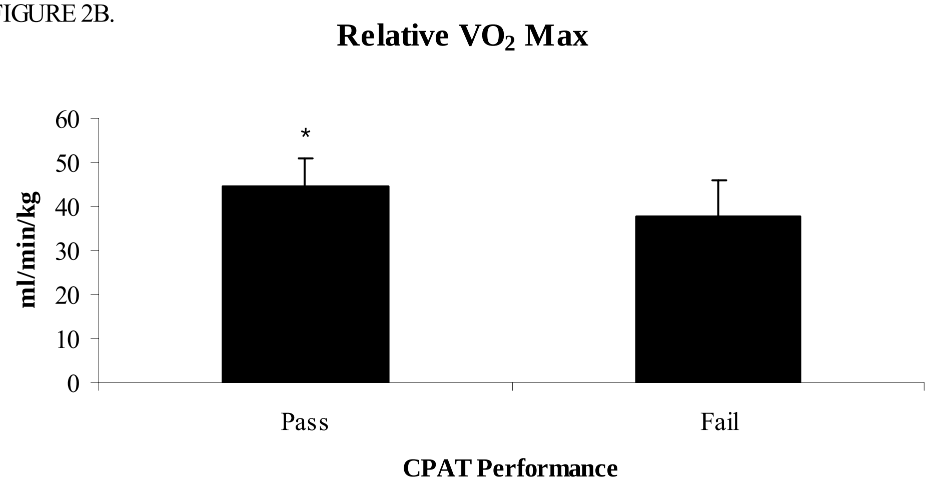

FIGURE 2 - Absolute VO_2max (l/min, A) and relative VO_2max (ml/kg/min, B) in those who pass (≤ 10 min & 20 sec) versus those who fail (> 10 min & 20 sec) the Candidates

Physical Ability Test (CPAT). The asterisk (*) signifies values are significantly different than in those who fail the CPAT, ($P < 0.01$). Values are presented as mean ± SD.

Appendix D- Raw Data

Obs	Subject_ ID	Sex	Height	Weight	Age	Chest_ Press_ 1_RM	Leg_Press_ 1_RM	Right_Knee_ Extension_ 1_RM	Left_Knee_ Extension_ 1_Rm	__Body_ Fat	BMI
1	1	0	186.9	90.46	19	215	600	280	260	0.19404	26.2315
2	2	0	172.8	70.58	33	200	665	200	215	0.13656	23.8151
3	3	0	177.2	97.54	30	143	720	260	255	0.29241	31.1987
4	6	0	184.8	83.90	29	190	615	270	255	0.19189	24.7934
5	7	0	177.2	116.50	33	180	835	305	310	0.30463	37.0371
6	8	0	175.3	130.90	26	162	725	326	280	0.40172	42.8899
7	9	0	181.9	63.80	22	130	660	202	190	0.14271	19.3270
8	10	0	172.2	82.70	37	240	600	225	210	0.21148	27.7765
9	13	0	182.1	73.60	20	195	650	200	223	0.13301	21.9732
10	14	0	183.0	126.50	37	170	780	305	273	0.32378	37.7597
11	15	0	197.5	147.70	24	250	1000	337	338	0.32409	37.5763
12	16	0	178.7	92.90	39	135	715	225	235	0.27893	29.3257
13	17	0	173.2	69.70	21	165	630	165	170	0.21574	23.0168
14	19	0	188.2	90.00	38	.	.	.	.	0.22640	25.6849
15	20	0	183.5	88.90	38	225	675	290	295	0.21340	26.4910
16	26	0	183.5	88.10	28	240	860	338	338	0.12696	26.4225
17	30	0	176.7	94.40	21	200	685	280	275	0.21386	30.1523
18	31	0	186.2	92.70	20	238	720	326	278	0.17047	26.9697
19	35	0	172.7	74.20	23	165	850	260	247	0.16268	25.1355
20	37	0	198.0	124.20	19	190	745	305	295	0.28187	31.0852
21	38	0	189.0	100.90	27	275	885	320	305	0.19463	28.4959
22	40	0	186.3	82.00	36	220	700	250	225	0.20042	23.5537
23	43	0	181.6	93.30	31	230	910	305	288	0.16414	28.3327
24	48	0	181.2	83.60	30	200	585	250	216	0.19471	25.7434
25	50	0	178.2	84.00	23	165	645	225	235	0.19104	26.4745
26	52	0	177.3	78.20	21	155	720	255	255	0.18969	24.7923
27	21	1	180.2	64.80	23	105	290	130	135	0.24032	19.8680
28	27	1	162.8	60.60	23	100	410	113	123	0.28510	23.0491
29	39	1	163.4	67.90	37	105	501	215	200	0.21619	25.6404
30	42	1	164.5	53.00	33	90	430	152	158	0.18779	19.5463
31	45	1	183.2	81.00	29	141	540	252	220	0.19498	24.2855
32	51	1	178.9	78.50	30	110	550	221	237	0.27059	24.5656
33	53	1	156.1	63.70	33	120	495	140	150	0.26271	26.3212

Obs	Absolute_ VO2	Relative_ VO2	HR_Max	Peak_ Power	Relative_ Peak_Power	Total_ Work	Relative_ Total_Work	Mean_ Power	Relative_ Mean_Power
1	4.199	46.5182	205	730.79	7.9090	15021.83	162.574	500.728	5.41913
2	.	38.6000	194	623.70	8.7476	12162.21	170.578	405.407	5.68593
3	.	32.3000	200	773.16	7.9298	14604.06	149.785	486.802	4.99284
4	3.229	38.5626	194	527.21	6.1589	11297.26	131.977	376.575	4.39924

5	3.219	27.0863	176	.	.	.	.	.	.
6	2.811	21.4731	203	903.78	7.0388	.	.	.	.
7	3.278	51.3806	201	691.96	10.5869	13550.83	207.326	451.694	6.91087
8	3.081	37.2552	186	.	.	.	.	.	.
9	4.270	58.0158	192	790.81	10.6149	14168.65	190.183	472.288	6.33944
10	4.044	31.9663	188	1141.49	8.8612	18263.90	141.778	608.797	4.72595
11	4.703	31.9121	192	.	.	.	.	.	.
12	3.567	38.3975	183	835.53	8.8136	15457.24	163.051	515.241	5.43504
13	3.136	45.0987	200	748.44	10.5638	14657.02	206.874	488.567	6.89580
14	3.194	35.4914	192	.	.	.	.	.	.
15	3.470	39.1142	188	.	.	.	.	.	.
16	4.531	51.4369	193	960.27	10.5686	19205.34	211.373	640.178	7.04576
17	3.787	40.1193	.	919.08	9.6847	16710.53	176.086	557.018	5.86952
18	4.167	44.9441	206	919.08	9.7774	18381.58	195.549	612.719	6.51829
19	4.306	58.0328	196	737.85	9.5950	12744.72	165.731	424.824	5.52437
20	4.502	36.2495	196	995.57	7.9076	16039.76	127.401	534.659	4.24669
21	4.046	40.1071	192	983.80	9.7406	20570.43	203.668	685.681	6.78892
22	3.256	39.8788	175	861.42	10.5825	.	.	.	.
23	4.395	47.1954	186	1070.89	11.5025	21829.60	234.475	727.653	7.81583
24	3.516	42.1454	186	815.52	9.7434	17422.49	208.154	580.750	6.93847
25	4.051	48.3270	204	861.42	10.4414	17587.25	213.179	586.242	7.10596
26	3.468	44.3478	203	763.74	9.6676	14927.68	188.958	497.589	6.29860
27	2.515	38.8820	197	461.30	7.1299	8072.83	124.773	269.094	4.15911
28	2.552	42.1118	186	378.93	6.1514	8390.57	136.211	279.686	4.54035
29	3.215	47.4480	188	489.55	7.0949	10096.93	146.332	336.564	4.87774
30	2.238	42.2278	187	550.74	10.4110	8031.65	151.827	267.722	5.06090
31	3.587	44.3765	203	789.63	9.7606	14356.94	177.465	478.565	5.91551
32	3.200	40.8496	198	763.74	9.6432	14233.37	179.714	474.446	5.99048
33	3.121	49.0068	194	508.38	7.8940	8755.38	135.953	291.846	4.53177

Obs	Fatigue_ Index	Right_Leg_ Peak_Power	Left_Leg_ Peak_Power	HR0	HR30	HR1	HR15	HR2	HR25	HR3	SBO1	SBP2	SBP3	DBP1	DBP2	DBP3
1	0.55556	667.34	628.44	134	150	158	163	164	169	172	160	165	179	62	59	60
2	0.70000	815.77	768.67	135	156	167	174	179	182	184	192	207	212	84	86	93
3	0.66667	764.19	738.03	.	.	.	.	.	.	.	.	.	.	.	.	.
4	0.57143	802.65	866.66	121	139	159	165	171	175	175	163	172	151	80	85	98
5	.	882.22	758.71	156	176	179	182	187	191	191	179	200	196	82	107	107
6	.	1040.98	897.45	175	187	197	.	.	.	.	54	.	.	39	.	.
7	0.58333	600.28	677.94	168	174	180	181	183	185	188	142	144	167	73	66	64
8	.	662.13	667.02	132	140	148	153	156	159	162	184	215	200	80	85	88
9	0.66667	668.40	612.14	126	141	150	152	161	166	165	145	151	168	67	68	76
10	0.70000	785.10	715.93	121	152	167	176	.	.	.	175	.	.	114	.	.
11	.	1207.06	1212.60	147	160	171	175	181	185	188	.	.	245	.	.	82
12	0.60000	821.29	703.76	140	146	160	163	168	172	172	187	198	207	80	84	89
13	0.50000	692.07	633.96	130	158	164	171	173	178	180	204	210	213	68	75	78
14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15	.	812.39	803.24	138	150	163	167	170	178	180	234	242	237	94	92	90
16	0.50000	988.06	931.07	162	168	174	178	182	182	183	157	167	165	81	80	81
17	0.63636	959.95	877.68	148	152	160	162	169	168	172	199	213	217	53	64	57
18	0.54545	1048.88	1041.75	130	149	158	161	162	168	167	202	210	202	58	62	64
19	0.63636	649.72	597.17	.	.	.	.	.	.	.	.	.	.	.	.	.
20	0.66667	1042.80	1005.92	144	168	175	180	183	186	189	210	221	232	75	80	83
21	0.54545	1125.02	1169.05	142	146	155	163	168	168	168	165	185	187	73	72	71
22	.	906.58	822.80	142	157	165	171	174	178	179	200	206	210	81	82	81
23	0.53846	1000.80	945.12	136	154	157	159	161	162	162	184	194	195	74	78	79
24	0.54545	746.25	725.09	145	157	160	169	167	172	172	164	167	142	66	74	77
25	0.50000	774.08	715.61	139	146	155	158	163	165	167	187	189	205	75	80	78
26	0.54545	841.17	840.80	139	157	162	166	169	172	174	214	216	214	83	81	84
27	0.62500	380.42	380.89	140	169	179	183	188	192	194	192	202	200	67	68	71
28	0.57143	373.35	358.02	.	.	.	.	.	.	.	.	.	.	.	.	.
29	0.50000	508.00	482.12	150	163	169	174	175	178	178	217	215	213	102	89	93
30	0.66667	477.56	493.21	150	169	174	179	183	188	189	167	200	174	67	97	87
31	0.63636	841.12	763.00	142	154	167	173	179	181	182	201	195	199	86	88	84
32	0.54545	564.24	581.61	164	174	180	180	183	185	186	174	185	182	95	89	87
33	0.55556	353.49	355.22	149	157	161	165	170	175	180	191	200	204	80	83	89

Obs	RPP1	RPP2	RPP3	SMHRMAX	PHRMAX	Stair_ Climb	Transtition_ 1	Hose_ Drag	Transtition_ 2	Equipment_ Carry
1	25280	27060	30788	172	0.83902	186.00	15.90	41.20	19.10	36.40
2	32064	37053	39008	184	0.94845	187.60	19.60	56.20	24.50	93.90
3	.	.	.	.	.	.	.	.	.	.
4	25917	29412	26425	175	0.90206	183.74	21.65	39.49	23.56	50.73
5	32041	37400	37436	191	1.08523	186.41	18.10	32.69	26.43	47.56
6	10638	0	0	197	0.97044	.	.	.	.	.
7	25560	26352	31396	188	0.93532	186.17	17.86	31.60	20.57	45.04
8	27232	33540	32400	162	0.87097	185.13	17.60	37.16	20.36	50.46
9	21750	24311	27720	166	0.86458	184.13	16.43	28.59	19.05	45.92
10	29225	.	.	176	0.93617	188.20	28.20	41.39	27.52	63.06
11	.	.	46060	188	0.97917	188.79	21.11	35.65	25.10	57.53
12	29920	33264	35604	172	0.93989	184.48	19.72	32.71	16.29	45.66
13	33456	36330	38340	180	0.90000	186.03	19.75	42.03	22.81	52.68
14	.	.	.	.	.	184.93	17.40	24.90	19.96	42.29
15	38142	41140	42660	180	0.95745	183.09	17.27	25.10	20.00	45.58
16	27318	30394	30195	183	0.98387	185.24	13.62	23.15	16.60	40.76
17	31840	35997	37324	172	0.83495	183.04	16.11	27.29	20.09	43.03
18	31916	34020	33734	168	0.85714	183.36	12.34	21.14	15.38	35.16
19	.	.	.	.	.	185.94	19.39	24.44	20.28	45.54
20	36750	40443	43848	189	0.96429	185.38	17.20	33.15	21.08	50.37
21	25575	31080	31416	168	0.87500	186.86	17.88	25.40	20.99	44.33
22	33000	35844	37590	179	1.02286	183.50	14.50	21.30	17.56	38.95
23	28888	31234	31590	162	0.87097	182.93	13.34	19.50	15.05	37.72
24	26240	27889	24424	172	0.92473	185.99	16.68	22.16	20.76	43.66
25	28985	30807	34235	167	0.81863	183.17	14.96	21.05	15.64	39.22
26	34668	36504	37236	174	0.85714	185.21	18.84	24.83	19.94	48.92
27	34368	37976	38800	194	0.98477	185.82	16.56	42.89	19.48	55.11
28	.	.	.	.	.	184.58	17.49	40.21	22.12	51.30
29	36673	37625	37914	178	0.94681	187.12	17.51	36.75	20.33	53.79
30	29058	36600	32886	189	1.01070	189.41	28.20	62.98	26.52	68.15
31	33567	34905	36218	182	0.89655	186.60	21.77	34.51	22.20	51.19
32	31320	33855	33852	186	0.93939	184.52	16.59	52.53	18.09	45.91
33	30751	34000	36720	180	0.92784	186.46	21.07	38.50	23.47	52.68

Obs	Transtition_ 3	Ladder_ Raise	Transtition_ 4	Forcible_ Entry	Transtition_ 5	Search	Transtition_ 6	Rescue
1	17.30	15.20	14.00	14.80	13.80	45.50	13.90	26.80
2	23.60	31.10	23.30	26.40	19.80	74.80	25.00	50.80
3	.	.	.	.	.	.	.	.
4	21.50	18.80	18.05	16.36	17.76	103.90	20.19	30.48
5	23.22	14.63	19.56	12.17	19.13	88.74	24.63	70.86
6	.	.	.	.	.	.	.	.
7	18.02	20.03	17.29	25.49	19.66	74.90	18.23	20.23
8	19.34	19.69	17.73	15.69	17.61	58.00	20.28	44.18
9	20.13	18.31	17.03	15.53	17.56	50.93	34.01	31.81
10	26.19	21.63	24.03	17.24	25.24	89.17	26.99	44.58
11	23.70	16.70	23.83	14.80	20.20	63.30	22.06	31.93
12	18.54	16.69	17.93	12.53	16.72	54.25	17.56	29.77
13	19.95	20.99	19.36	13.03	16.63	55.93	19.84	25.05
14	17.61	15.20	17.39	11.56	17.56	52.45	17.36	.
15	19.07	14.50	18.14	12.50	16.50	50.73	18.02	34.81
16	15.18	19.06	13.11	11.22	12.48	27.79	13.00	26.80
17	17.39	15.90	15.81	12.61	14.17	34.50	17.21	37.27
18	15.62	14.19	13.70	9.39	12.80	25.53	14.43	24.54
19	20.96	19.14	18.69	10.20	16.39	40.49	17.04	27.41
20	18.66	19.00	17.21	15.44	16.12	76.97	16.59	20.46
21	17.05	12.59	16.26	10.96	16.51	50.49	17.19	30.16
22	17.01	12.38	16.03	10.60	14.32	37.63	15.54	27.71
23	16.28	15.43	14.14	10.32	13.47	41.12	14.08	26.88
24	18.97	17.62	16.13	12.00	16.00	48.13	17.99	25.36
25	15.35	14.30	13.52	10.98	12.62	38.19	14.33	32.24

26	19.71	19.21	15.18	15.37	17.38	64.00	18.26	24.96
27	18.98	28.21	18.95	49.75	18.70	67.74	22.70	.
28	20.71	18.32	18.63	41.80	17.20	50.34	19.49	113.56
29	17.91	20.45	16.77	25.41	16.50	48.04	19.51	53.66
30	25.30	26.50	21.63	28.56	21.83	85.99	26.33	100.71
31	19.98	16.96	16.37	28.02	18.51	58.48	19.26	29.54
32	17.20	19.27	16.47	18.04	15.11	51.54	15.34	39.11
33	22.13	29.09	20.02	32.75	19.90	47.65	20.73	46.53

Obs	Transtition_ 7	Ceiling_ Breach	Total_ Time	Pass_ Fail
1	14.10	58.00	532.00	0
2	22.30	91.50	770.40	1
3	.	.	.	1
4	23.47	57.72	647.40	1
5	21.74	63.86	669.73	1
6	.	.	.	1
7	.	.	.	1
8	23.23	83.89	630.35	1
9	20.84	46.81	567.08	0
10	29.43	83.75	736.62	1
11	25.88	62.20	632.78	1
12	18.18	40.82	541.85	0
13	20.70	54.59	589.37	0
14	.	.	.	1
15	21.00	46.70	543.01	0
16	15.59	51.30	484.90	0
17	20.32	112.81	587.55	0
18	15.54	35.94	449.06	0
19	20.33	39.31	525.55	0
20	19.60	56.31	583.54	0
21	19.21	48.65	534.53	0
22	16.24	51.84	495.11	0
23	15.74	51.10	487.10	0
24	20.30	62.25	544.00	0
25	16.13	52.49	494.19	0
26	20.88	103.60	616.29	0
27	.	.	.	1
28	24.10	56.29	696.14	1
29	20.47	69.70	623.92	1
30	34.07	106.52	852.70	1
31	19.51	52.35	595.25	0
32	18.49	55.97	584.18	0
33	23.56	55.07	639.61	1

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