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Physiological indicators in the prediction of firefighting ability

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PHYSIOLOGICAL INDICATORS
IN THE PREDICTION
OF FIREFIGHTING ABILITY

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By

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ABSTRACT

PHYSIOLOGICAL INDICATORS IN THE PREDICTION OF FIREFIGHTING ABILITY

by A. Douglas Moberg

The purpose of this study was to determine the physiological indicators in the prediction of firefighting ability in 36 male professional firefighters aged 21 to 36 years. Physiological measurements included combined arm and leg ergometry for determination of maximal oxygen uptake and anaerobic capacity, isokinetic strength at 60°/sec of leg, shoulder, and arm flexion and extension, body weight, relative fat, and body somatotype. A timed field test comprised of standardized firefighting tasks determined highly skilled (117 to 137 sec), average (140 to 155 sec), and less skilled (158 to 193 sec) firefighter groups. The descriptive characteristics differed significantly ($p \leq .05$) between groups on leg flexion strength, arm extension strength, arm flexion strength, and anaerobic capacity. Stepwise regression analysis identified arm flexion strength as accounting for 26% of the variance between subjects in firefighting ability. Multiple discriminant analysis identified discriminant function 1 (DF1) as representing strength and body type variables and discriminant function 2 (DF2) as representing strength and metabolic variables. DF1 accounted for 74.3% of the variance, while DF2 accounted for the remaining 25.7% resulting in correct classification of 80.6% of the firefighters. In conclusion, superior upper body strength and a body type that reflects muscularity and low body fat characterize the highly skilled firefighters.

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CHAPTER I

Introduction

This chapter is divided into the following sections: background for the study, statement of the problem, approach to the problem, statement of the hypotheses, delimitations, limitations, definition of terms, statistical analysis, and summary.

Background for the Study

Astrand and Rodahl (1986) suggest that the ideal way to perform physical work is to perform it dynamically, with brief work periods interrupted by brief pauses, but for professional firefighters, a near maximal cardiovascular response for extended periods of time and under extreme environmental conditions is often required. The Los Angeles City Fire Department (1971) has described the job requirements of an active-duty firefighter as follows:

> Physical performance calling for above average ability, endurance, and superior condition, including occasional demand for extraordinary strenuous activities in emergencies, under adverse environmental conditions, and over extended periods of time; requires running, walking, difficult climbing, jumping, twisting, bending, and lifting over 25 pounds; pace of work is typically set by the emergency situation. (p. 1)

The emergency situation often requires a near maximal heart rate (75 to 95% MHR) for extended periods of time (one to three hours); therefore, it would seem imperative that firefighters be required to maintain a high degree of physical fitness (Lemon & Hermiston, 1977).

In the study by Lemon and Hermiston (1977), it was suggested that professional firefighters, especially the older firefighters who still participated in fire suppression, should consider devoting more time to developing and maintaining a higher level of fitness. It was found that the percent of body fat increased with age, VO_2 max decreased progressively across the increasing age group, and there was a progressive decrease in strength measurements across the age groups in arm strength and lower body strength.

In a study by Davis, Dotson, and Santa Maria (1982), 26 physical performance variables were assessed on 100 professional firefighters and correlated against time measures of five sequentially performed firefighting tasks and against heart rates collected during performance of the firefighting tasks. Statistical analysis revealed that the fractionated time (elapsed time to complete each task and total time to complete all tasks) and heart rate data were accounted for by physical work capacity and resistance to fatigue. The variables best predicting physical work capacity were maximal heart rate, sit-ups, grip strength, age, and submaximal oxygen pulse (mlO_2/beats/min). Resistance to fatigue was best predicted by lean body weight, maximal heart rate, final treadmill grade, age, and percent fat.

Physiological profiles have been done for numerous sports in order to develop training programs for the athletes involved in those sports. It would seem that the same should be done for professional firefighters in order to facilitate the development of training programs to ensure their ability to perform in emergency situations.

Statement of the Problem

The purpose of this study was to determine the physiological characteristics associated with firefighting ability.

Approach to the Problem

Thirty-six male firefighters were studied to assess the following physiological variables: anaerobic capacity (AC), body weight (BW), leg strength (LS), arm strength (AS), shoulder strength (SS), maximal oxygen uptake (VO_2 max), relative fat (RF), and body somatotype (X rating and Y rating).

Statement of the Hypotheses

1. There will be no significant relationship between anaerobic capacity and the ability to perform standard firefighting tasks.

2. There will be no significant relationship between body weight, relative fat, and the ability to perform standard firefighting tasks.

3. There will be no significant relationship between leg strength, arm strength, shoulder strength, and the ability to perform standard firefighting tasks.

4. There will be no significant relationship between maximal oxygen uptake (VO_2 max) and the ability to perform standard firefighting tasks.

5. There will be no significant relationship between body somatotype and the ability to perform standard firefighting tasks.

Delimitations

This study was delimited to 36 healthy male volunteers between the ages of 21 to 36 years. All subjects were full-time professional firefighters.

Limitations

The factors in this study that were not controlled included the following: pretesting activity, nutritional status, genetic make-up, and motivational level of each subject. The study was also limited by environmental conditions (air temperature, relative humidity, and air quality) during the field testing portion of the study.

Assumptions

It was assumed that there was no change in physiological variables measured during the time elapsed between the laboratory testing and the performance of standardized firefighting tasks. It was also assumed that all subjects gave a best effort in both the laboratory testing and during the firefighting tasks performance.

Definition of Terms

Anaerobic Capacity (AC). Anaerobic capacity reflects the glycolytic (lactic) component and the alactic component of energy release (Tharp, Newhouse, Uffelman, Thorland, & Johnson, 1985). It represents the total work completed during a 30-second period (kgm/30-sec) and is calculated by the following formula:

> (0.06 kgm leg resistance x kg of body weight x 6 x the number of revolutions of the crank arm in a 30-sec period) + (0.05 kgm arm resistance x kg body weight x 6 x the number of revolutions of the crank arm in a 30-sec period) (Bar-Or, 1978; Tharp et al., 1985; Tharp, Johnson, & Thorland, 1984).

Body Somatotype (X and Y). Body somatotype is defined by coordinates X and Y. It is composed of a coordinate grid superimposed over a somatochart. Individual coordinate points can be plotted on the chart using the following formulas: X = ectomorphy - endomorphy, and Y = (2 x mesomorphy) - (endomorphy + ectomorphy). Variable X is a descriptive measure of linearity - fatness and variable Y is a descriptive measure of muscularity (Ross & Wilson, 1973).

Body Weight (BW). Body weight is the total weight of all body tissues expressed in kilograms (kg).

Leg Strength, Arm Strength, and Shoulder Strength (LS, AS, and SS). Leg, arm, and shoulder strength are the absolute peak torque values expressed in ft/lbs for the dominant leg and arm in extension and flexion movements at 60°/

sec. (Isokinetic Joint Testing & Exercise: A handbook for Cybex II+ and U.B.X.T., 1983).

Maximal Oxygen Uptake (VO_2 max). Maximal oxygen uptake is the point at which the oxygen consumption plateaus and shows no further increase (or increases only slightly) with an additional workload. It is also referred to as the maximal oxygen consumption, maximal oxygen uptake, maximal aerobic power, or, simply, max VO_2 (McArdle, Katch & Katch, 1986).

Relative Fat (RF). Relative fat is the portion of the body weight composed of adipose tissue and is calculated by the following formula:

RF = [(4.57/Db) - 4.142] x 100 (Brozek, Grande, Anderson, & Keys, 1963).

Residual Lung Volume (RV). Residual volume is the air that remains in the lungs after a maximal expiration. Measuring body composition by hydrostatic weighing requires that correction be made in the equation for residual lung volume (Noble, 1986).

CHAPTER II

Review of Literature

Introduction

Firefighting is distinguished from other occupations by the fact that firefighters cannot control the physical demands of their work environment. Two of the most demanding environmental stressors affecting firefighters are temperature and breathing atmosphere. Not only are firefighters confronted by heat at the fire scene, reaching temperatures as high as 232°C (450°F) inside a burning structure, but they are exposed to a secondary heat environment created by their protective equipment. In protecting the firefighter from heat and fire, the protective equipment also entraps the body heat generated by physical activity.

Although many deadly gases are present at a fire scene, the most dangerous is carbon monoxide which is present in high concentrations during the overhaul of the interior fire scene. This is also the time that firefighters are likely to remove their breathing equipment and expose themselves to the carbon monoxide (Davis, Biersner, Barnard, & Schamadan, 1982).

In order to determine which physiological attributes are most effective in adapting to these environmental stressors, a review of literature was done. Studies that dealt with occupational exposure of firefighters, health and fitness programs of fire departments, and firefighting performance and physiological profiles were reviewed.

Physiological Responses to Occupational Exposure and Equipment Heat

In a study designed to investigate heart rate, oxygen uptake, and thermal changes in working firefighters, Duncan, Gardner, and Barnard (1979) tested 11 firefighters on a treadmill at 4.0 $km \cdot h^{-1}$ on a 10% grade for 15 minutes. The first two tests were conducted in the laboratory, and the third test was conducted in a sauna. For the first test (BL) the subjects wore their normal lightweight uniforms. The second and third tests (TL, TS) were done with the subjects wearing their protective turnout uniforms, boots, and breathing devices. Heart rates after 15 minutes of exercise increased significantly for each trial (BL=99.2 $\pm$ 3.3, TL=136.4 $\pm$ 4.3 and TS=172.7 $\pm$ 3.2 beats/min). Oxygen uptake values were similar for tests conducted on firefighters in turnouts, but were significantly higher than the test conducted on firefighters in the lightweight uniform (BL=7.13 $\pm$ 0.41, TL=10.47 $\pm$ 0.75 and TS=10.80 $\pm$ 0.59 $cm^3 \cdot kg^{-1} \cdot min^{-1}$). The data showed that significant stress was placed on the firefighters by the weight and insulating properties of the protective equipment. This was especially true while working in the heat.

Carbon Monoxide (CO)

Thirty-six men were chosen at random from the Oklahoma City Fire Department by Sammons and Coleman (1974) and paired as closely as possible (age, weight, height, race, smoking habits, and family history of cardiovascular and pulmonary disease) with members of local military reserve units. During the five months of the study, blood was drawn from each test and control subject every 28 days. Analysis of the blood samples revealed that the firefighters had significantly higher levels of COHb (carboxyhemoglobin), LDH (lactic dehydrogenase), LDH-S (heat stable lactic dehydrogenase), HBD (hydroxybutyric dehydrogenase), and CPK (creatine phosphokinase) than their paired controls. The mean COHb value for the firefighters was 5.0 mgm% as compared to 2.3 mgm% for the control group. From these results it was determined that the test group exceeded the COHb content that would be achieved if the subjects had labored 1400 minutes in an atmosphere of 42 mg/M^3 CO which is the maximum allowable COHb saturation under NIOSH (National Institute of Occupational Safety and Health) guidelines. The exhibited changes in enzyme activities of this test group suggested myocardial damage.

Blood samples were drawn as firefighters left the fire atmosphere at 124 fires in Baltimore during a six month period in a study by Radford and Levine (1976). A total of 519 samples were drawn, and 57 samples were drawn from a control group that was not exposed to the fire atmosphere. A comparison of COHb levels between nonexposed controls and of firefighters showed a COHb level of 2.12% in the control group and a level of 4.53% in the firefighter group. This is comprable to the 2.3% level in the control group and 5.0% level in the firefighters reported by Sammons and Coleman (1974). Blood COHb levels were lowest in those firefighters who wore their self-contained breathing devices continuously during exposure to the fire atmosphere. Nonwearers had significantly higher levels. Pulse rates that were associated with elevated COHb levels were elevated in a large number of firefighters immediately after exposure, but cause and effect could not be determined from the data.

In a study to examine determinants of carbon monoxide uptake, Griggs (1977) selected 20 male volunteers from a basic firefighting class at North Carolina State Fire College and Pump School. The subjects who ranged in age from 19 to 48 years performed a series of firefighting evolutions in a smoke-filled house with a CO level of about 300 ppm. The firefighting evolutions were performed twice, once with, and once without self-contained breathing apparatus. The use of breathing apparatus provided full protection from COHb uptake but contributed to significantly increased heart rates. Results showed that even though CO levels may be low, the high ventilatory rates due to physical exertion and the excitement of firefighting activities dramatically increases the uptake of carbon monoxide. This represents an additional risk to the firefighter as carbon monoxide has been identified as an agent that might contribute to myocardial ischemia.

Self-Contained Breathing Apparatus

Raven, Davis, Shafer, and Linnebur (1977) studied 15 male firefighters (mean age = 31.0 years) under four separate conditions on a maximal treadmill stress test. The four conditions were: (1) without wearing a self-contained breathing apparatus (SCBA); (2) wearing a SCBA, but without wearing the face mask; (3) wearing a SCBA, the face mask, and with the regulator in the demand breathing mode; (4) wearing a SCBA, the face mask, and with the regulator in the pressure-demand breathing mode. Results showed a 20% decrease in work performance during conditions 2, 3, and 4. The decrease was attributed to the weight of the SCBA (15.8 kg).

The maximal dynamic work load decreased 35% while wearing a SCBA in a study by Louhevaara, Smolander, Tuomi, Karhonen, and Jaakkola (1985). The subjects were 13 firefighters with a mean age of 30.0 years who performed sequential exercise tests on a treadmill, both with and without a SCBA. Submaximal exercise oxygen consumption and heart rate increased significantly while wearing a SCBA. Mean ventilation rate was 68% and oxygen consumption was 83% of maximal values attained without the SCBA. Ventilation and gas exchange were seriously disturbed by the shoulder harness of the SCBA, which prevented free motion of the thorax.

In a 1983 study by Manning and Griggs, five professional firefighters performed standard firefighting evolutions to determine exertion levels while wearing no self-contained breathing apparatus, a light SCBA, and a heavy SCBA.

The subjects, males between the ages of 21 and 31 years, were timed while advancing a 1.5-inch hose line through a predetermined route. Each firefighter performed the drill three times utilizing no SCBA, a light SCBA, and a heavy SCBA. Exertion levels were measured as a function of the heart rate increase relative to the maximum predicted heart rate determined by a standard treadmill exercise test. Heart rates increased rapidly to 70% to 80% of maximum within the first minute and then plateaued at 90% to 100% until completion of the drill. The type of SCBA used did not apparently affect the heart rate increases. Although the results were not indicative of the exertional cost of wearing an SCBA, they did document the high exertional cost of the firefighting task. This study also demonstrated that high temperatures caused increases in heart rates faster than total oxygen consumption. Since heart rate is a major determinant of myocardial oxygen demand, this is of concern to firefighters with coronary heart disease (Manning & Griggs, 1983).

Heart Rate and Ischemia

In a study by Barnard and Duncan (1975), 35 firefighters between the ages of 23 to 42 years were observed for electrocardiographic and heart rate responses during a normal 24-hour work day. Fifteen to 30 seconds after the sounding of an alarm, heart rate showed a mean increase of 47 beats/min, and one minute after the alarm, when the firefighters were on the engine answering the alarm, heart rate values were still 30 beats/min above that recorded before the alarm sounded. High heart rates (175-195 beats/min) were observed during the first 3 to 5 minutes of a fire. The ECG changes observed in response to the alarm displayed S-T segment changes that, in most cases were not classical ischemic responses (≥1 mm S-T depression), but could represent subendocardial ischemia (horizontal S-T depression is the most important electrocardiographic indication of coronary insufficiency).

Similar results were found by Kuorinka and Korhonen (1981) in their study of 22 firefighters whose ECGs were recorded during a 24-hour work day. Results showed a mean peak heart rate of 61 beats/min which the authors concluded to be virtually the same as the Barnard and Duncan (1975) study. The increase in heart rate was attributed to normal arousal plus abrupt physical activity.

In an attempt to determine if the apparent high incidence of coronary heart disease in firefighters was related to the usual risk factors or to the work environment of the firefighters, Barnard, Gardner, Diaco, and Kattus (1975) tested 90 randomly selected firefighters. The subjects were between the ages of 40 to 59 years and were investigated for electrocardiographic response to near-maximal exercise, blood pressure, serum cholesterol, and smoking habits. The authors came to the following conclusions:

> The observations suggest that ischemic heart disease may be job-associated. Recent electrocardiographic recordings obtained from firefighters while on the job show that for the most part they are relatively sedentary, however, there are frequent occasions when they must exert themselves maximally. Extremely high heart rates recorded immediately after the alarm, during the anticipation phase while riding on the truck and for prolonged periods during actual firefighting indicate an emotional stress. In addition the men are exposed to thermal stress as well as inhalation pollution. All of these factors may be related to the pathogenesis of ischemic heart disease and may be independent of atheromatous deposits in the coronary arteries. (p. 695)

These results were surprising in that the subjects tested were from a population that had undergone thorough preemployment medical examinations. The observed incidence of ischemic stress tests suggested that ischemic heart disease may be job associated.

Nine firefighters with ischemic responses to near-maximal stress testing were randomly selected by Barnard, Gardner, and Diaco (1976) to present follow-up data from previous studies that suggested that ischemic stress tests were job related. An ischemic ECG change was defined as, "at least 1 mm of horizontal or down slanting depression of the ST segment observed either during exercise or in the 5-minute, post-exercise recovery period" (p. 818). The subjects were given the choice to undergo cardiac catheterization and angiography which included right and left heart catheterization, selective coronary angiography, left ventricular angiography, coronary sinus catheterization, and atrial pacing. The data from this study suggested that the ischemic heart disease found in these subjects was not due to coronary artery disease, but was due to job stress which had a detrimental effect on the myocardium. Ischemia in the case of firefighters could be related to fireground exposure to carbon monoxide or elevated catecholamines due to job related stress.

Health and Fitness Programs

Cady, Thomas, and Karwasky (1985) studied the results of a physical fitness program initiated by the Los Angeles County Occupational Health Service for the Los Angeles County Fire Department. The program was begun in 1970 and the goals were to significantly increase muscular strength and endurance, to reduce the magnitude of modifiable coronary heart disease risk factors (smoking, blood pressure, blood lipids, and cardiovascular fitness), and to reduce insurance claims for orthopedic and cardiovascular injuries and illnesses. The program consisted of a thorough physical examination, individual exercise prescriptions, and physical fitness and nutritional counseling. By 1982, physical work capacity (PWC) had increased an average of 16%. Longitudinal and cross-sectional data showed a reversal in the decline of work capacity and a retardation in the decline in strength and flexibility associated with aging.

In 1971 the Los Angeles City Fire Department instituted a mandatory physical fitness program. The effectiveness of this program was evaluated in a study by Barnard and Anthony (1980). To determine changes in cholesterol, blood pressure, and body weight, 300 medical examinations were randomly selected for analyses. Results showed a significant reduction in serum cholesterol, no significant effect on systolic blood pressure, but a significant reduction in diastolic blood pressure. There were no significant changes in body weight. The authors concluded that a health maintenance program could be utilized to increase fitness levels and reduce atherosclerotic heart disease risk factors.

In order to evaluate physiological adaptation and job performance changes, Adams, Yanowitz, Chandler, Specht, Lockwood, and Yeh (1986) randomly selected 51 professional firefighters to participate in a supervised 14-week exercise program. Twenty-six men served as a control group by maintaining their normal lifestyles while 25 men participated in aerobic, anaerobic, and stretching exercises. The two groups underwent testing for maximal oxygen consumption (VO_2 max), resting and exercise ECG, hydrostatic weighing, pulmonary function, strength (Cybex), and blood lipid analysis before and after the 14-week training program. Three timed firefighting evolutions were also performed both before and after training. Following training, the exercise group displayed a significant increase in VO_2 max, arm and leg endurance, and job-related skills. It was concluded that "a regular exercise program coupled with healthy lifestyle instruction is beneficial in improving exercise capacity and job performance among firefighters and should be implemented in all fire departments" (p. 344).

To determine the cardiovascular effects of an exercise program, Puterbaugh and Lawyer (1983) divided 27 firefighters into 3 groups, using one group as a control and providing exercise programs for the other two groups. Although the exercise programs were similar, one of the exercise groups was supervised. After 12 weeks the unsupervised exercise group showed an average increase of 19% in maximal oxygen uptake (VO_2 max). The supervised exercise group showed an average increase of 20% VO_2 max, while the control group decreased an average of 2%. It was concluded that increased VO_2 max should allow the firefighter to perform work tasks with a lower heart rate which should reduce the risk of myocardial ischemia.

In the study by Lemon and Hermiston (1977), 20 male firefighters were randomly selected to assess the energy cost of four firefighting evolutions. The subjects were divided into two groups based upon their maximum oxygen uptake (VO_2 max) with group 1 < 40 ml/kg/min and group 2 > 40 ml/kg/min. Five subjects from each group were randomly selected to perform the four firefighting evolutions. Results indicated that group 2 (>40 ml/kg/min) might be able to supply a greater percentage of total O_2 aerobically than group 1 (<40 ml/kg/min). From this data it was suggested that a greater maximum oxygen uptake allowed the subjects to contribute a greater percentage of total energy demand aerobically, which would decrease the physiological toll taken on individuals. This would be of special concern to firefighters, allowing the more aerobically fit to work at a greater intensity or longer at the same intensity than the less aerobically fit.

<u>Firefighting Performance and Physiological Profiles</u>

The purpose of the study by Davis, et al. (1982) was to determine the relationship between simulated firefighting tasks and physical performance measures. To determine this relationship, 100 professional firefighters were tested for 26 physical performance variables and five timed standard firefighting evolutions. Correlation analysis revealed that fractionated time (elapsed time to complete each task and the total time to complete all tasks) and heart rate data were accounted for by physical work capacity and resistance to fatigue. The physical performance variables that were the best predictors for physical work capacity were maximal heart rate (M=184.0±10.38 beats/min), sit-ups (M=36.9±11.67), grip strength (M=47.4±5.99 kg), age (M=33.1±7.63 yr), and submaximal oxygen pulse (M=14.3±2.38 ml$_{O2}$/beats/min) which reflects the efficiency of the oxygen transport system during steady-state muscular work. Resistance to fatigue was best predicted by lean body weight (M=65.8±5.98 kg), maximal heart rate (M=184.0±10.38 beats/min), final treadmill grade using the Balke protocol (M=17.8±3.08%), age (M=33.1±7.63 yr), and percent fat (M=21.1±6.69%). After analysis of data, the profile suggested by the physical performance variables indicated that firefighters must possess an efficient cardiovascular system, high aerobic capacity, and a minimum of negative factors associated with age and body fat.

Summary

The review of literature has revealed that firefighters are subjected to a hostile environment where they are exposed to extreme temperatures and high levels of carbon monoxide. These factors, coupled with elevated catecholamine levels result in a high percentage of firefighters with ischemic heart disease independent of atheromatous deposits in the coronary arteries. Observations suggest that ischemic heart disease may be job related. If this is true, it reinforces the need for firefighters to maintain a high level of fitness reflected by an efficient cardiovascular system, a high aerobic capacity, a high degree of muscular endurance, and a minimum of negative factors associated with age and body fat. It appears that these physiological attributes are most effective in adapting to the extreme environmental stressors confronted by firefighters.

CHAPTER III

Methods

Introduction

This chapter provides information on the subjects, testing methodology, and the statistical analysis.

Subjects

The subjects were males between the ages of 21 to 36 years. There were a total of 12 thesis variables measured so that a minimum of 36 subjects were needed for the statistical analysis (Jackson, 1984). Subjects were full-time professional firefighters employed by Santa Clara County Central Fire Protection District, Los Gatos, California. All subjects completed and signed a consent form (Appendix A) and a health/medical history questionnaire (Appendix B) approved by the Human Subjects Institutional Review Board of San Jose State University.

Testing Methodology

The testing of the subjects was divided into field testing utilizing standardized firefighting tasks and laboratory testing utilizing standardized laboratory instrumentation.

Field Testing

The field test consisted of the following firefighting tasks.

1. Ladder Raise - Carry, raise, and extend 7.32 m (24 ft) extension ladder to the second-floor balcony of the training tower.
2. Hose Bundle Carry - Lift and carry a 22.1 kg (49 lb) bundle of hose that was 30.5 m (100 ft) long and 3.81 cm (1.5 in) in diameter up the ladder to the second-floor balcony. Proceed with the hose bundle, via interior stairs, to the third-floor of the training tower.

3. Hose Pull - Utilizing a utility line, pull a 19.1 kg (42 lb) roll of 15.2 m (50 ft) long and 6.35 cm (2.5 in) diameter hose from the ground to the third-floor balcony.

4. Simulated Rescue - Carry a 68.2 kg (150 lb) dummy from the third floor to the second floor of the training tower.

5. Simulated Forcible Entry - Strike a rubber block with a 3.4 kg (7.5 lb) fire axe 30 strokes using a full-swing, over-the-head chopping motion.

Testing took place while the firefighters were on duty, and each firefighter wore complete protective equipment consisting of helmet, self-contained breathing apparatus (SCBA), and turnout coat. The entire protective equipment ensemble weighed a total of 23.6 kg (52 lb). All subjects were encouraged to simulate emergency conditions and complete the evolution as rapidly as possible while maintaining fireground safety precautions. The time to complete the entire evolution was recorded for each subject. Testing took place at the Campbell Fire Department Drill Tower, Campbell, California. Paramedics were available from the adjacent fire station in case of any medical emergency.

Laboratory Testing

All subjects were tested in the following order.

1. Strength measurements
    - leg extension and flexion at 60°/sec
    - forearm extension and flexion at 60°/sec
    - shoulder extension and flexion at 60°/sec
2. Anaerobic capacity
    - combined arm and leg ergometry
3. Body composition
    - body weight

- relative fat

4. Maximal oxygen uptake (VO_2 max)

   - combined arm and leg ergometry

Strength Measures

Leg Strength

The Cybex II+ isokinetic dynamometer was used to measure leg strength. The subjects were seated on the Cybex bench with the thigh, hip, and chest stabilized by velcro straps. The dynamometer's axis of rotation was adjusted so it aligned with the subject's anatomical axis of rotation at the knee joint of the dominant leg (determined from kicking preference). The distal end of the lever arm was then strapped to the subject's leg proximal to the malleoli of the ankle (Isolated Joint Testing & Exercise: A Handbook for Using the Cybex II+ and the U.B.X.T., 1983).

Leg strength was determined from the subject's leg extension and flexion through a 90^0 range of motion. After a warm-up of three submaximal trials, the subjects executed three maximal extensions and flexions at 60^0/sec. The highest peak torque values were measured and used (Gilliam, Villanacci, Freedson, & Sady, 1979; Housh, Thorland, Johnson, Tharp, Cisar, Refsell, & Ansorge, 1984).

Arm Strength

The Cybex II+ isokinetic dynamometer with U.B.X.T. attachments was used to measure arm strength. Subjects were placed in a seated position on the U.B.X.T. bench, with their upper body stabilized by a velcro strap. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the elbow joint. The effective input arm was determined by measuring from the lateral epicondyle to the thumb webspace on the subject's dominant arm (determined by throwing preference). The length of the testing accessory was then adjusted accordingly (Isolated Joint Testing & Exercise: A Handbook for Using the Cybex II+ and the U.B.X.T., 1983).

Arm strength was determined from the subject's arm extension and flexion through a 90° range of motion. After a warm-up of three submaximal trials, the subject executed three maximal extensions and flexions at 60°/sec. The highest peak torque values were measured and used (Gilliam et al., 1979; Housh et al., 1984).

Shoulder Strength

The Cybex II+ isokinetic dynamometer with U.B.X.T. attachments was used to measure shoulder strength. The subject was placed in a reclining position on the U.B.X.T. bench, with his upper body stabilized by a velcro strap. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the shoulder joint of the dominant shoulder (determined by throwing preference). The "effective input arm" length was determined by bringing the subject's arm to full extension above the shoulder, and then measuring from the glenohumeral joint to the thumb webspace of the subject's arm. The length of the testing accessory was then adjusted accordingly (Isolated Joint Testing & Exercise: A Handbook for Using the Cybex II+ and the U.B.X.T., 1983).

Shoulder strength was determined from the subject's shoulder extension and flexion through a 180° range of motion. After a warm-up of three submaximal trials, the subject executed three maximal extensions and flexions at 60°/sec. The highest peak torque values were measured and recorded (Gilliam et al., 1979; Housh et al., 1984).

Anaerobic Work Measurements

The Wingate Anaerobic Test (WAnT) was used to measure anaerobic capacity. A 650 Monarch bicycle and Monarch arm ergometer measured upper and lower body anaerobic indicators simultaneously. Prior to the start of each test, the seat of the bicycle ergometer was adjusted so that the subject's legs were near full extension when pedaling. The axis of the crank arm on the arm ergometer was aligned with the subject's glenohumeral joint (Seals & Mullin, 1982; Reybrouck, Heigenhauser, & Faulkner, 1975). The test was proceeded by four minutes of warm-up followed by two minutes of rest. At a given command the subject began pedaling as fast as possible while the researchers increased the resistance to 0.05 and 0.06 X BW (kg), for arms and legs respectively, within the first two to three seconds (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). As soon as the workload was set, the thirty second test began during which time the subject was encouraged to give a maximal effort. The workload and elapsed time were carefully monitored throughout the time period. Anaerobic capacity was calculated as the total work (kgm/30sec) completed (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). The test reflects the combined arm and leg (A&L) anaerobic capacity.

Body Composition

Body composition was determined by underwater weighing with correction made for residual lung volume using the helium dilution method. Body weight in kilograms (kg) was measured on a platform scale for all subjects. Underwater weighing was performed in a metal tank in which a webbed sling was suspended from a Chatillon scale. Subjects performed 6 to 10 trials of underwater weighing with the average of three scores, $\pm$ 0.05 kg of each other, used to represent the underwater weight (Cisar, Johnson, Fry, Housh, Hughes, Ryan, & Thorland, 1987). Relative fat was calculated from the formula of Brozek et al. (1963).

Anthropometry

Body build characteristics were determined by obtaining anthropometric measurements and height. Height was measured using a wall scale with a Broca plane. Lange calipers were used to measure skinfold thickness at triceps, subcapular, suprailiac, and calf sites (Behnke & Wilmore, 1974). The average of at least two repeated trials, within 0.5 mm of each other, were used as the representative score (Cisar et al., 1987).

Biacromical and biiliac diameters of the elbow and the knee were measured with a broad blade anthropometer to the nearest 0.1 cm. Circumferences of the flexed arm and calf were measured with a Lufkin metal tape, fitted with a Gullick handle, to the nearest 0.1 cm. Anthropometric sites used were those described by Behnke and Wilmore (1974). These measurements were used to calculate body somatotypes using anthropometric rating methods as described by Heath and Carter (1967). The three-component somatotype rating (endomorphy, mesomorphy, and ectomorphy) were converted to bidimensional score, X and Y, as described by Ross and Wilson (1973).

Aerobic Capacity Test

Aerobic capacity was measured using a combined arm and leg cranking task on a 650 Monarch bicycle ergometer and a Monarch arm ergometer. Subjects were fitted with headgear which supported a Hans-Rudolph respiratory valve and a mouth piece. Inhaled air passed through a Parkinson-Cowan CD-4 Dry Test meter and then into the respiratory valve. A potentiometer connected to an Apple II+ computer was used to record the volume of inspired air. Expired air passed out of the Hans-Rudolph valve into a mixing chamber where the air sample was analyzed.

A Wilmore-Costill Spinner Valve (WCSV) system was used to analyze the oxygen (FeO_2) and carbon dioxide ($FeCO_2$) content of the expired air. A sample of expired gases passed through the mixing chamber into the WCSV system before passing into the analyzers. A Beckman LB-2 Medical Gas Analyzer measured the percent carbon dioxide expired and an Applied Electrochemical S-3A analyzer determined the percent oxygen expired. The analyzers were calibrated before each test and during every stage (three minutes) of the test with a standard gas sample. Data for inspired and expired air was collected every minute of the test. Heart rate was monitored using a Narco physiograph recorder. The electrocardiogram was printed out for the last ten seconds of every minute of the test at the speed of 25 m/sec. Three surface electrodes were used to monitor the electrical patterns of the subject's heart.

The subject began the test seated on the bicycle ergometer with the seat height adjusted to near full leg extension. The axis of the crank arm of the arm ergometer was aligned with the subject's glenohumeral joint (Seals & Mullin, 1982; Reybrouck et al., 1975). Every 3 minutes the resistance was increased by 1.0 kp (0.25 kp arms and 0.75 kp legs) until voluntary exhaustion. A metronome was used to set pedaling cadence while a Gralab clock was used to maintain time intervals. The test was terminated for any one of the following reasons: (1) the subject requested to stop the test, (2) failure of the heart rate to increase with the increasing workloads, (3) pain or fatigue as indicated by a decreasing coordination or pallor, (4) any abnormalities on the ECG reading, or (5) equipment failure (ACSM, 1986).

A postexercise ECG strip was obtained prior to the removal of the electrodes after the subject's heart rate had decreased to/or below 120 beats/min. Expired ventilation rate (VE) was calculated from the inspired ventilation rate (VI). Oxygen consumption (VO_2) and carbon dioxide production (VCO_2) rates were calculated from VI, VE, FEO_2, and $FECO_2$ values.

Statistical Analysis

Descriptive statistics (M + SD) were used to describe the overall characteristics of the group. Pearson product-moment correlations were utilized to examine the relationships between the descriptive characteristics. One-way analysis of variance and Tukey post hoc tests were used to determine the mean differences across skill levels on the descriptive characteristics. Subjects were subdivided into equal groups of highly skilled (117 to 137 sec), average (140 to 155 sec), and less skilled (158 to 193 sec) firefighters based on field times. A full-model and stepwise multiple regression analysis was used to examine the relationship between the physiological variables and performance time.

Multiple discriminant analysis was used to determine the degree to which the physiological variables discriminated between highly skilled, average, and less skilled firefighters on the dependent performance measures. The alpha level for statistical significance was $p \leq .05$.

CHAPTER IV

Analysis of Data

Introduction

This chapter includes analysis of data, summary and discussion of findings, conclusions, weaknesses, and recommendations for future research

Analysis of Data

Table 1 summarizes the descriptive characteristics of the 36 male subjects that were tested in the study.

The descriptive characteristics of the subjects by groups and the results of the one-way analysis of variance and Tukey post hoc tests used to examine the mean differences in the descriptive characteristics of the subjects across ranked groups are summarized in table 2. There were no significant differences between groups in BW, RF, leg extension strength, shoulder strength, VO_2 max, X rating, and Y rating. Although there were no significant ($p \leq .05$) differences between highly skilled (group 1), average (group 2), and less skilled (group 3) subjects on the above mentioned variables, the highly skilled subjects tended to be lower in relative fat and X rating (linearity - fatness). The highly skilled subjects tended to be higher on Y rating (muscularity), leg extension strength, and VO_2 max. There were significant differences between highly skilled (group 1) and average (group 2) subjects on leg flexion strength, arm flexion strength, and A & L anaerobic capacity. Group 1 had significantly greater leg flexion strength, significantly greater arm flexion strength, and significantly greater A & L anaerobic capacity than group 2. Also, there were significant differences between highly skilled (group 1) and less skilled (group 3) subjects on arm extension strength and arm flexion strength. Group 1 had significantly greater arm extension strength and

Table 1

Descriptive Characteristics of the Subjects

n = 36	Mean	SD
Age (yr)	30.22	3.88
Height (cm)	179.74	6.88
Body Weight (kg)	84.35	8.91
Relative fat (%)	16.19	4.51
Leg strength (ext, ft/lbs)	169.83	28.15
Leg strength (flex, ft/lbs)	107.50	17.95
Shoulder strength (ext, ft/lbs)	92.08	16.31
Shoulder strength (flex, ft/lbs)	51.17	17.27
Arm strength (ext, ft/lbs)	57.19	14.50
Arm strength (flex, ft/lbs)	52.75	8.87
Anaerobic capacity (kgm/30sec)	2310.35	329.00
Maximal oxygen uptake (ml/kg)	38.26	5.78
X rating	-3.29	2.06
Y rating	3.95	2.86
Field time (sec)	147.47	19.39

Table 2

Descriptive Characteristics of the Subjects Across Firefighting Ability Groups

	Groups[a]		
Characteristics	1	2	3
n	13	12	11
Body weight (kg)	85.49 ± 2.95	81.96 ± 1.85	85.62 ± 2.80
Relative fat (%)	13.90 ± 1.52	17.58 ± 0.84	17.37 ± 1.17
Leg strength (ext, ft/lbs)	177.23 ± 7.99	162.50 ± 5.68	169.83 ± 4.69
Leg strength (flex, ft/lbs)[b]	115.77 ± 4.24	98.17 ± 4.91	107.91 ± 2.99

Note. Values are M ± SEM.

[a]Subjects subdivided into equal groups based on field times with group 1 being highly skilled, group 2 average, and group 3 less skilled.

[b]One-way analysis of variance significant at $p \leq .05$ and Tukey post hoc difference between groups 1 and 2.

Table 2

Descriptive Characteristics of the Subjects Across Firefighting Ability Groups (continued)

	Groups[a]		
Characteristics	1	2	3
n	13	12	11
Shoulder strength			
(ext, ft/lbs)	100.15 ± 4.68	88.92 ± 3.90	86.00 ± 4.78
Shoulder strength			
(flex, ft/lbs)	44.49 ± 6.12	55.89 ± 3.11	53.91 ± 4.66
Arm strength			
(ext, ft/lbs)[c]	65.85 ± 4.71	55.00 ± 2.48	49.36 ± 3.54
Arm strength			
(flex, ft/lbs)[d]	59.46 ± 2.27	49.92 ± 1.90	47.91 ± 2.19

Note. Values are M ± SEM.

[a]Subjects subdivided into equal groups based on field times with group 1 being highly skilled, group 2 average, and group 3 less skilled.

[c]One-way analysis of variance significant at $p \leq .05$ and Tukey post hoc difference between groups 1 and 3.

[d]One-way analysis of variance significant at $p \leq .05$ and Tukey post hoc difference between groups 1 and 2, and groups 1 and 3.

Table 2

Descriptive Characteristics of the Subjects Across Firefighting Ability Groups (continued)

	Groups[a]		
Characteristics	1	2	3
n	13	12	11
Anaerobic capacity (kgm/30 sec)[b]	2493.08 ±84.80	2093.33 ±77.05	2331.16 ±89.39
Maximal oxygen uptake (ml/kg)	40.99 ± 1.63	36.30 ± 1.92	37.19 ± 0.96
X rating	-2.47 ± 0.74	-3.99 ± 0.46	-3.50 ± 0.96
Y rating	4.81 ± 0.71	3.75 ± 0.79	3.16 ± 1.00
Field time	127.31 ± 1.99	148.17 ± 1.44	170.55 ± 3.19

Note. Values are M ± SEM.

[a]Subjects subdivided into equal groups based on field times with group 1 being highly skilled, group 2 average, and group 3 less skilled.

[b]One-way analysis of variance significant at $p \leq .05$ and Tukey post hoc difference between groups 1 and 2.

significantly greater arm flexion strength than group 3.

Table 3 presents the zero-order correlation matrix between the descriptive characteristics for the overall group of subjects. The intercorrelation coefficients between the predictor variables exhibited a wide range of values (r = .01 to .91).

Table 4 summarizes the full-model and the stepwise multiple regression analyses for the prediction of firefighting ability from the variables for all groups of subjects. The full-model analysis resulted in a F = 1.40, R = .57, SEE = 18.46 seconds. The stepwise multiple regression analysis only identified arm flexion strength as a significant variable in the model. This single variable accounted for 26% of the variance in ranking of firefighting ability. The remaining variables accounted for an additional 6% of the variance in firefighting rank. It should be noted that three variables, relative fat, X rating, and leg flexion strength could not be statistically forced into the regression model.

The rotated discriminant function coefficients for each discriminant function are shown in table 5. The relative importance of each predictor variable to the discriminant function is represented by these functions. Discriminant function 1 (DF1), comprised of strength and body type variables, accounted for 74.3% of the variance between groups. Discriminant function 2 (DF2), strength and metabolic variables, accounted for 25.7% of the variance between groups.

Table 6 summarizes the discriminant functions as evaluated by group means (group centroids). Discriminant function 1 tended to discriminate between the highly skilled (group 1) and the average (group 2) firefighters (1.3020 vs -0.1623). Discriminant function 2 tended to discriminate the highly skilled (group 1) and the average (group 2) from the less skilled (group 3) firefighters (0.2768 and 0.5342 vs -0.9100). Those variables most highly related to DF1 were shoulder flexion strength, X rating, Y rating, arm flexion strength, and relative fat.

Table 3

Zero-Order Correlation Matrix for the Descriptive Characteristics of the Subjects (n = 36)

	BW	RF	LSE	LSF	SSE	SSF	FASE	FASF	ALAC	VO2	X	Y	FLD
Body Weight	1.00												
Relative Fat	.53	1.00											
Leg Strength (ext)	.82	.28	1.00										
Leg Strength (flex)	.74	.18	.76	1.00									
Shoulder Strength (ext)	.24	-.16	.39	.39	1.00								
Shoulder Strength (flex)	.51	.71	.24	.11	-.12	1.00							
Arm Strength (ext)	-.03	-.32	.01	.16	.22	-.22	1.00						
Arm Strength (flex)	.18	-.24	.26	.43	.47	-.19	.80	1.00					
Anaerobic Capacity	.60	-.04	.69	.59	.49	-.05	.23	.37	1.00				
Maximal 02 Uptake	-.43	-.66	-.24	-.13	.01	-.62	.15	.10	.11	1.00			
X Rating	-.51	-.76	-.28	-.16	.05	-.91	.22	.14	.02	.63	1.00		
Y Rating	-.10	-.22	.02	.17	.29	-.42	.20	.34	.15	.20	.05	1.00	
Field Time	-.10	.17	-.24	-.26	-.32	.10	-.36	-.51	-.24	-.16	-.10	-.12	1.00

Note. $r \geq .33$ significant at $p \leq .05$

Table 4

Full-Model and Stepwise Multiple Regression and Beta Coefficient Analysis for the Prediction of Firefighting Ability (n = 36)

Predictor variable	Full-Model* Regression coefficient	Beta coefficient	Stepwise** R	Stepwise** F
1. Arm strength (flex, ft/lbs)	-1.1952	-0.55	.51	11.89**
2. Leg strength (ext, ft/lbs)	-0.2336	-0.34	.52	6.17
3. Body weight (kg)	0.5087	0.23	.54	4.43
4. Maximal oxygen uptake (ml/kg)	-0.6642	-0.20	.55	3.36
5. Shoulder strength (flex, ft/lbs)	-0.1380	-0.12	.56	2.76
6. Arm strength (ext, ft/lbs)	0.1015	0.08	.56	2.25
7. Y rating	0.5360	0.08	.57	1.90
8. Shoulder strength (ext, ft/lbs)	-0.9826	-0.08	.57	1.62
9. Anaerobic capacity (kgm/30sec)	0.0052	0.09	.57	1.40
(Constant)	228.9804			

Note. Field test (sec) = 206.21 - FASF(1.11)

(FASF - Arm strength flex)

* $P \leq .24$; R = .57, SEE = 18.46 sec, *F = 1.40

** $P \leq .01$; R = .51, SEE = 16.93 sec, **F = 11.89

Table 5

Rotated Discriminant Matrix for Prediction of Firefighting Ability

Variable	Function 1	Function 2
X rating	2.248[a]	-0.275
Shoulder strength (flex, ft/lbs)	2.180[a]	-0.060
Y rating	0.775[a]	0.165
Arm strength (flex, ft/lbs)	0.583[a]	0.120
Relative fat	-0.044[a]	0.029
Leg strength (ext, ft/lbs)	-0.468	1.054[b]
Anaerobic capacity (kgm/30sec)	0.685	-1.030[b]
Leg strength (flex, ft/lbs)	0.456	-0.709[b]
Arm strength (ext, ft/lbs)	-0.266	0.665[b]
Shoulder strength (ext, ft/lbs)	-0.100	0.569[b]
Maximal oxygen uptake (ml/kg)	0.300	0.411[b]
Body weight (kg)	0.025	0.048[b]

[a]Denotes discriminant function, function 1, with which predictor variable was most highly related.

[b]Denotes discriminant function, function 2, with which predictor variable was most highly related.

Variables most highly related to DF2 were leg flexion strength, leg extension strength, A & L anaerobic capacity, arm extension strength, shoulder extension strength, VO_2 max, and body weight. Although strength indices were the biggest discriminating factors, VO_2 max and anaerobic indices were important in discriminating the highly skilled (group 1) and average (group 2) groups of subjects from the less skilled (group 3) subjects.

Table 7 illustrates the classification results of the prediction equation developed from the multiple discriminant analysis. There was excellent classification of firefighters into group 1, group 2, and group 3. The percent of firefighters correctly classified was 80.6%.

Summary of Findings

There were no significant differences observed in the descriptive characteristics of the subjects across the ranked groups of firefighters for body weight, residual fat, leg extension strength, shoulder strength (extension and flexion), VO_2 max, X rating, and Y rating. There were significant differences between highly skilled (group 1) and average (group 2) subjects on leg flexion strength, arm flexion strength, and A & L anaerobic capacity. Group 1 had significantly greater leg flexion strength, arm flexion strength, and A & L anaerobic capacity than group 2. There were also significant differences between highly skilled (group 1) and less skilled (group 3) subjects on arm extension strength and arm flexion strength. Group 1 had significantly greater arm extension strength and arm flexion strength than group 3. The stepwise multiple regression analysis identified only arm flexion strength as a significant variable in the model accounting for 26% of the variance in ranking of firefighting ability. Multiple discriminant analysis identified discriminant function 1 (DF1) as a strength and body type function and discriminant function 2 (DF2) as a strength

Table 6

Discriminant Functions Evaluated by Centroids (means)

Group	Function 1	Function 2
1	1.302	0.277
2	-1.162	0.534
3	-0.271	-0.910

Table 7

Group Classification Results of Multiple Discriminant Analysis

		Predicted group membership		
Actual group	n	1	2	3
Group 1	13	10	1	2
		(76.9%)	(07.7%)	(15.4%)
Group 2	12	2	10	0
		(16.7%)	(83.3%)	(00.0%)
Group 3	11	1	1	9
		(09.1%)	(09.1%)	(81.8%)

Note. Percent of firefighters correctly classified was 80.56%.

and metabolic function. Discriminant function 1 (DF1) accounted for 74.3% of the variance between groups and discriminant function 2 (DF2) accounted for 25.7% of the variance between groups. The discriminant analysis correctly classified 80.6% of the firefighters. In group 1 there was 76.9% correct classification, while in group 2 there was an 83.3% correct classification, and in group 3 an 81.8% correct classification. The prediction equation developed from the discriminant analysis appears to do an excellent job of classification for all three levels of firefighting ability.

Discussion of Findings

The primary purpose of this study was to determine the physiological characteristics associated with firefighting ability. With this information it might then be possible to utilize key physiological indicators in the prediction of firefighting ability. For the 36 subjects tested in this study the variables that accounted for 74.3% of the variance between groups were variables that comprised the strength and body type. The remaining 25.7% of the variance between groups were variables that comprised the strength and metabolic variables.

The physiological variables that discriminated between the highly skilled subjects (group 1) and the average subjects (group 2) were X rating, shoulder flexion strength, Y rating, arm flexion strength, and relative fat. This would indicate that superior upper body strength and a body type that reflects muscularity and low body fat characterizes those firefighters with the fastest field times (group 1). The physiological variables that discriminated between the slower subjects (group 3) and the faster subjects (groups 1 and 2) were leg extension strength, leg flexion strength, arm extension strength, shoulder extension strength, body weight, A & L anaerobic capacity, and maximal oxygen uptake (VO_2 max). Again, superior strength, specifically leg strength, distinguished those firefighters with the fastest field times (groups 1 and 2). Although superior overall body strength was the largest discriminating factor between groups, metabolic variables (VO_2 max and anaerobic capacity) were important factors in discriminating between the faster subjects (groups 1 and 2) and the slower subjects (group 3). This suggests that for firefighters to perform at optimal levels on the fireground, they must also possess superior aerobic and anaerobic capacities. These results are comparable to the Davis, et al. (1982) study in which the physical performance variables that best predicted physical work capacity were identified as maximal heart rate, sit-ups, grip strength, age, and submaximal pulse. The variables that best predicted resistance to fatigue were identified as lean body weight, maximal heart rate, final treadmill grade, age, and percent fat.

Based upon the prediction equation developed from the multiple discriminant analysis, it was possible to correctly classify 80.56% of the subjects into their predicted group. This suggests that it may be possible to use selected physiological variables to predict how an individual will perform on a standardized firefighting field test, and in turn, how that individual will physically perform as a firefighter. This has importance in that it would enable fire departments to develop physical fitness programs that would ensure that their employees perform optimally on the fireground. This, of course, would be dependent upon the field test being a stressor of selected physiological variables and not a measure of developed firefighting skill. It is also dependent upon the field test being representative of actual firefighting tasks.

Conclusions

Within the limits of this study the following conclusions were made:

(1) The descriptive characteristics of the overall group of subjects were similar and differed only on leg flexion strength, arm extension strength, arm flexion strength, and A & L anaerobic capacity. The highly skilled subjects had significantly greater leg flexion strength, arm flexion strength, and A & L anaerobic capacity than the average group of subjects. The highly skilled subjects had significantly greater arm flexion and extension strength than the less skilled subjects.

(2) Stepwise regression identified arm flexion strength as accounting for 26% of the variance between subjects. Other variables measured accounted for 6% of the variance in firefighter ability.

(3) Discriminant function 1 (X rating, Y rating, shoulder flexion strength, arm flexion strength, and relative fat) accounted for 74.3% of the variance between groups. Discriminant function 2 (leg extension strength, A & L anaerobic capacity, leg flexion strength, arm extension strength, shoulder extension strength, maximal oxygen uptake, and body weight) accounted for 25.7% of the variance between groups.

(4) Discriminant analysis correctly classified 80.6% of the firefighters as highly skilled, average, and less skilled firefighters.

Weaknesses

The primary weakness of the study was the firefighter field test. Since this portion of the testing was administered by fire department training personnel, it was impossible to have control over the reliability of the testing process. In addition, motivation and firefighter experience are factors to be considered in the field test results.

It is believed that the weak correlation between the field test and the physiological variables may be due to the length of the field test. There was possibly too small of a range between the fastest subject (1.95 min) and the slowest subject (3.25 min) for a valid correlational analysis. In the Davis, et al. (1982) study, subjects were required to carry the hose pack to the fifth-floor of the training tower, pull the hose roll to the fifth-floor window, and carry/drag the dummy from the fifth-floor to ground level. This resulted in a fast time of 4.22 minutes and a slow time of 27.33 minutes.

Recommendations for Future Research

Within the limits of this study the following recommendations are made:

(1) Future research should examine lactic acid tolerance to determine any relationship between lactic acid tolerance and firefighting ability.

(2) Future research should examine the physiological indicators of firefighting ability in female subjects.

(3) Future research should attempt to validate the prediction model of this study with other samples of subjects.

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APPENDIX A

STUDY TO INVESTIGATE THE CONTRIBUTION OF SELECTED PHYSIOLOGICAL INDICATORS IN THE PREDICTION OF FIREFIGHTING ABILITY

STATEMENT OF INFORMED CONSENT - - FOR MUSCULAR STRENGTH, ANAEROBIC CAPACITY, BODY COMPOSITION AND SIZE, AND CARDIORESPIRATORY ENDURANCE

Invitation to Participate

You are invited to participate in a study investigating the effects of muscular strength, anaerobic work indices, body composition, and cardiorespiratory (heart-lung function) endurance characteristics on firefighting ability. This study will be conducted at the San Jose State University campus.

Basis for Selection

You have been selected as a participant because you are a healthy male aged 21 to 36 years who is employed by Santa Clara County Central Fire Protection District. Should you decide to participate, your response to a health history questionnaire will be reviewed by an exercise physiologist and, if satisfactory, you will be asked to participate in the tests described below.

Purpose of the Study

The purpose of this study is to investigate the contribution of selected physiological indicators in the prediction of firefighting ability.

Explanation of Procedures

Muscular Strength Tests (approximately 20 minutes required)

This test will involve measuring the maximal strength for extension of your dominant leg at the knee joint and dominant arm at the shoulder joint using a Cybex II+ isokinetic dynamometer. The Cybex II+ will not generate any resistance at slower speeds of leg or arm movement. At faster speeds of movement the resistance will match the force you produce. For the leg strength test, you will be in a sitting position on a bench and secured at the thigh with a velcro strap for stabilization. Your leg will be attached to a lever arm of the machine by a velcro strap at the ankle. For the arm and shoulder strength tests, you will be in a reclining position with your upper body stabilized with velcro straps and your hand around a hand grip. All strength tests will begin with three to four warm-up trials, followed by three consecutive maximal extension trials at a moderate speed of movement for determination of leg, shoulder, and arm strength.

Anaerobic Capacity Test (approximately 10 minutes required)

The anaerobic capacity test will consist of pedaling a stationary bicycle and arm cranking simultaneously against resistance as fast as possible for 30 seconds. The test will be preceded by a warm-up period and followed by a cool-down period. The bicycle is fitted with toe clips to reduce the risk of slipping off the pedal. You will begin pedaling against a very light resistance and on the command "GO" will begin pedaling as fast as possible. The resistance will be increased to the appropriate level (based on your body weight) within the first 2-3 seconds of the test. Verbal encouragement will be given to motivate you to give a maximal effort.

Body Composition and Size Test (approximately 30 minutes required)

This portion will involve two types of testing: anthropometry and underwater weighing. Anthropometry involves measuring height, circumferences, diameters, and skinfold thicknesses at specific body sites. Underwater weighing involves three measures: body weight, body weight while underwater, and residual lung volume (the amount of air left in your lungs after you have fully exhaled). For this test you will be seated in a chair, breathing room air through a mouthpiece. At the end of a normal expiration a valve will be turned so you will breathe a mixture of helium and room air from the spirometer. Oxygen will be added to the spirometer as needed. After breathing this mixture for several minutes you will be asked to inhale fully and then exhale fully. The whole procedure will be repeated as necessary. To obtain body weight while underwater, you will be sitting in a 4 inch wide canvas sling which will be suspended from a scale so that you are about neck deep in water. The water will be about 82 to 85 degrees F. You will then tuck your knees up and bend your head forward so that you are completely submerged and blow as much air from your lungs as possible. You must try to remain in this position for 5 to 10 seconds before raising your head, to allow a scale reading to be made. These procedures will be repeated 6 to 10 times with rest intervals between each procedure.

Arm and Leg Cranking for Cardiorespiratory Endurance (approximately 45 minutes)

Your maximal oxygen consumption and ventilatory threshold will be determined from a test which will involve simultaneous pedaling on a stationary bicycle and arm cranking at progressively increasing levels of resistance. Your expired air will be collected through a mouthpiece connected to rubber tubing. Your heart rate will be monitored by three electrodes attached to your chest wall.

Following the measurement of a resting heart rate and blood pressure, you will begin pedaling and cranking against a light resistance at 60 rpm. Every three minutes the resistance will be increased in both the arms and the legs until you can no longer continue at the required pedaling rate of 60 rpm. The test will end when you indicate that you no longer wish to continue or your responses (heart function, respiration, and/or physical appearance) indicate that you should not continue or have reached your maximal effort. Following completion of this test, the resistance will be reduced so that you can recover comfortably.

Firefighting Performance Time

During the month of January, 1991 you will be required to perform a series of standardized firefighting tasks at the Campbell Drill Tower. These tasks will be performed while on duty and will be supervised by representatives of Central Fire District Training Division. Your overall performance time for these tasks will be obtained.

Risks and Discomforts

Underwater Weighing

The water quality in the tank is maintained daily, however there is the possibility of certain types of infection. This is very unlikely due to the daily chemical treatment and filtering of the water. Chlorine irritation, swallowing of water, and choking are also possible as in any pool situation. Plus, there may be some discomfort associated with submersion under water.

Residual Lung Volume

Some persons experience faintness and/or dizziness when performing the breathing procedures. Discomfort associated with this test may come from breathing through a mouthpiece with a noseclip in place.

Cardiorespiratory Endurance

Some discomfort and dryness in the mouth, throat, and chest as a result of restricted breathing may occur. You may feel lightheaded, fatigued, and slightly nauseous for a short time following this test. Also, you may experience the discomforts commonly associated with exercise: sweating, increased heart rate, increased breathing rate, and elevated body temperature. At or near maximal exercise you may experience abnormal blood pressure, fainting and/or dizziness, muscle fatigue or cramps, and abnormalities in heart beat. If abnormalities are detected in pulmonary function or electrocardiographic recordings, you will be excluded from this investigation.

Strength and Anaerobic Responses

You may experience some muscle soreness and fatigue following these tests as well as increased heart rate, increased breathing rate, elevated body temperature, sweating, and fatigue during the test.

Benefits from Participation in Study

You will benefit from this study by receiving feedback on muscular strength, anaerobic work indices, body composition, and cardiorespiratory endurance characteristics. The study will benefit the Fire Service in general by identifying those physiological indicators that may predict firefighting ability.

Assurance of Confidentiality

The results of this investigation may be used for research publication and presentation. Your right to confidentiality will be protected unless your express consent is granted prior to the publication or presentation of the data.

Withdrawal from the Study

You may withdraw your consent and discontinue your participation in this study at any time (including during the testing) without prejudice. You may also decline to answer any question or item on the health history questionnaire.

Testing will be supervised and conducted by Dr. Craig J. Cisar, Certified Exercise Test Technologist and Douglas Moberg, a graduate student. Certified CPR personnel will also be present during testing.

If you have any questions about the investigation now or during the testing, please feel free to ask. If additional questions come up later or in the case of an emergency, Douglas Moberg (408) 354-5504, Dr. Craig J. Cisar (408) 924-3018, or Dr. James Bryant (408) 924-3010 will be happy to answer them. In the case of any complaints during or after the testing, you may contact Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies and Research, at (408) 924-2480.

<u>Consent</u>

By signing this form, you are agreeing that:

(a) you have decided to participate in this study having read the information provided above;

(b) you understand the discomforts and risks involved;

(c) you understand that you can withdraw at any time; and

(d) you understand that your name will be kept confidential except with your express consent.

SIGNATURE ______________________________ DATE ____________

PRINT NAME ____

SIGNATURE OF WITNESS ____________________________________

SIGNATURE OF INVESTIGATOR _______________________________

APPENDIX B

PRE-EXERCISE TESTING
HEALTH STATUS QUESTIONNAIRE

____
Date

Name ______________________________ Occupation ____________________

Work Address ______________________________ Work Phone ____________________

Home Address ______________________________ Home Phone ____________________

Personal Physician ______________________________ Physician's Phone ____________________

Age ____________ Height __________ Weight __________ Sex ____________

Does the above weight indicate: a gain____, a loss____, no change____ in the past year? How many pounds?________

A. Joint-Muscle Status (Check areas in which you currently have problems)

Joint Areas	Muscle Areas
( ) Wrists	( ) Arms
( ) Elbows	( ) Shoulders
( ) Shoulders	( ) Chest
( ) Upper spine and neck	( ) Upper back and neck
( ) Lower spine	( ) Abdominal regions
( ) Hips	( ) Lower back
( ) Knees	( ) Buttocks
( ) Ankles	( ) Thighs
( ) Feet	( ) Lower leg
( ) Other ____________________	( ) Other ____________________

B. Health Status (Check if you previously or currently have any of the following conditions)

- ( ) High blood pressure
- ( ) Heart disease or dysfunction
- ( ) Peripheral circulatory disorder
- ( ) Lung disease or dysfunction
- ( ) Arthritis or gout
- ( ) Edema
- ( ) Epilepsy
- ( ) Multiple sclerosis
- ( ) High blood cholesterol or triglyceride levels
- ( ) Diabetes or blood sugar level abnormality
- ( ) Anemia
- ( ) Hernias
- ( ) Thyroid dysfunction
- ( ) Pancreas dysfunction
- ( ) Liver dysfunction
- ( ) Kidney dysfunction
- ( ) Neural dysfunction
- ( ) Acute infection
- ( ) Others that you feel we should know about ____________________ ____________________

C. Physical Examination History

Approximate date of your last physical examination ____________________

Physical problems noted at that time ____________________

When was the last time your resting electrocardiogram was evaluated? ____________________

Was it normal? Yes ( ) No ( ) If no, what was abnormal about it? ____________________

When was the last time you had your electrocardiogram evaluated during an exercise stress test?______ What heart rate did you reach during this exercise?______ Was the electrocardiogram normal? Yes ( ) No ( )
If no, what was abnormal about it? ____________________

Has a physician ever made any recommendations relative to limiting your ___ levels of physical exertion? Yes ( ) No ( )
If yes, what limitations were recommended? ____________________

D. Current Medication Usage (List drug name and the condition being managed)

Medication	Condition
____________________	____________________
____________________	____________________
____________________	____________________
____________________	____________________

E. Physical Perceptions - Indicate any unusual sensations or perceptions. (Check if you have recently experienced any of the following during or soon after physical activity (PA); or during sedentary periods (SED)

PA	SED		PA	SED	
( )	( )	Chest pain	( )	( )	Light headedness
( )	( )	Heart palpitations	( )	( )	Loss of balance
( )	( )	Unusually rapid breathing	( )	( )	Loss of breathing coordination
( )	( )	Overheating	( )	( )	Extreme weakness
( )	( )	Muscle cramping	( )	( )	Numbness
( )	( )	Muscle pain	( )	( )	Mental confusion
( )	( )	Joint pain	( )	( )	Other ____________________
( )	( )	Nausea			____________________

F. Family History (Check if any of your blood relatives - parents, brothers, sisters, aunts, uncles, and grandparents - have or had any of the following)

( ) Heart disease
( ) Heart attacks or strokes prior to age 50
( ) Elevated blood cholesterol or triglyceride level
( ) High blood pressure
( ) Diabetes

G. Current Habits (Check any of the following if they are characteristics of your current habits)

( ) Occupation is physically demanding
( ) Occupation is emotionally stressful and/or hectic
( ) In your leisure, you regularly do manual garden or yard work
( ) In your leisure, you regularly go for long walks
( ) You frequently ride a bicycle
( ) You engage in an exercise program more than once per week
If so, what does this consist of? ______________________________

____

____

( ) You smoke tobacco: ( ) cigarettes ( ) cigars ( ) pipe
- number per day (packs, cigars, pipeful) ______________________

H. Firefighting Experience

- Years of firefighting experience ______________________________