1993

Respirator wear and upper body work performance

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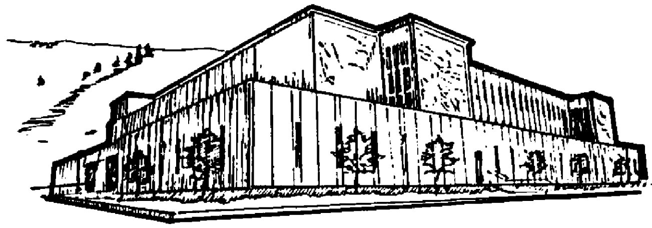

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RESPIRATOR WEAR AND UPPER BODY

WORK PERFORMANCE

by

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B.S. University of Montana, Missoula, 1991

Presented in partial fulfillment of the

requirements for the degree of

Master of Science

The University of Montana

1993

Approved ~~by~~:

Chairman, Board of Examiners

Dean, Graduate School

Dec. 7, 1993

Date

ABSTRACT

De Lorenzo-Green, Theresa M., M.S. November 1993

Health and Human Performance: Exercise Science

Respirator Wear and Upper Body Work Performance (83pp)

Director: Brian J. Sharkey, Ph.D.

Air-purifying respirators (APR) have been shown to affect treadmill performance via breathing resistance, dead space, heat stress, and weight. Studies of arm work have shown diminished levels of pulmonary ventilation that might exacerbate the effects of an APR. This study evaluated the effects of an APR on sustained arm work and attempted to predict the ability to perform while wearing an APR.

Nine male and nine female volunteers (ages 20-36) performed a battery of tests: pulmonary function tests; leg tests of maximal oxygen intake; arm tests of peak VO_2 with and without the APR (half-face APR with HEPA + OV/AG cartridges, airflow resistance = 36 mm H_2O at 42.5 L/min); muscular fitness tests; two sustained arm work tests with and without the APR; and a field (pack) test. Blood lactate measures were recorded. The sustained arm work test involved arm cranking at 60 rpm with the resistance adjusted to elicit a heart rate of 150 b/min. The field (pack) test consisted of a 4.83 km (3 mile) hike over level terrain while wearing a 20.5 kg (45 lb) pack.

Results showed that the APR significantly reduced peak arm work for the male-female (M-F) combined group and for the female (F) group (-2.24 mL/kg/min or 6.8% and -2.2 mL/kg/min or 7.4%; $p<.05$ respectively), but did not significantly reduce peak arm work for the male (M) group (-2.3 mL/kg/min or 6.3% $p = .232$). Sustained arm work showed no significant change for the M-F, M, and/or F group in spite of a 3.15 watt (5.6% reduction; $p = .07$) for the M-F group and a -3.01 watt (4.02%; $p = .193$), and a -3.29 watt (8.3%; $p = .244$) for the M and F groups. Predictors ($p<.05$) of sustained arm performance with the APR for combined M-F data included: arm peak VO_2 W and W/O APR ($r = .597, .542$), Arm VT (.654), pulmonary function measures (MVV = .554, PIF = .560, PEF = .541, $FEV_{1.0}$ = .730, FVC = .729), bench press (.694), Pack Test (-.708), height (.789), and weight (.732). Multiple regression analysis of sustained arm performance with the APR vs. $FEV_{1.0}$ and Pack Test yielded $R = .832$. Results indicate that arm work while wearing an APR can be predicted from pulmonary function and field performance measures.

ACKNOWLEDGMENTS

I would like to thank Dr. Brian Sharkey and Tara Rothwell for their support throughout this project. In addition, I would like to thank Dr. Kathy Miller and Dr. Donna Boggs for the suggestion they made regarding this manuscript.

Many thanks are owed to all the subjects who volunteered and were so patient and helpful throughout the study. Their help is what made the research possible. A special thanks to Kirk Rothwell for his assistance throughout the study.

Also, I'd like to thank Randall T. Green for his support, editorial comments and encouragement throughout this endeavor.

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Chapter One

THE PROBLEM

Introduction

Approximately 80,000 full-time and seasonal wildland firefighters in the United States often work long hours while being exposed to smoke and a variety of pulmonary irritants. The concentrations of these pulmonary irritants may exceed Occupational Safety and Health Administration (OSHA) standards, and evidence shows an increased risk of respiratory illnesses and reduced work performance due to smoke inhalation (Rothman, Ford, Baser, Hansen, O'Toole, Tockman & Strickland, 1991). The most widely used form of respiratory protection for wildland firefighters is a wet cotton bandanna worn over the mouth and nose. Although some states are considering imposing regulations for the use of air purifying respirators (APR) to protect firefighters, there is a need for more research regarding the effects on work performance while using a respirator, specifically while doing upper body work. In addition, there is a need to determine a simple clinical test to screen people for firefighting jobs with or without respirator wear (Wilson & Raven, 1989).

Firefighters engaged in fireline construction do vigorous work while exposed to the hazards of smoke. "The heavy physical demands of this work produce elevated pulmonary minute ventilation rates, increasing delivery of pulmonary irritants to the airways" (Rothman et al., 1991; Raven, Dodson & Davis, 1979). Exposure to these irritants may cause an increase in symptoms such as eye and nose irritation, sore throat, and wheezing. Although a respirator may provide a solution to the problem of smoke exposure, several studies have documented increased metabolic demand and decreased work performance while wearing a respirator (Raven et al, 1979; Thompson & Sharkey, 1966). As a result of an increased inspiratory and expiratory resistance placed on breathing, and an increase in metabolic demand needed to overcome this resistance during prolonged submaximal work, fitness and pulmonary function have become the focus of many studies (Thompson & Sharkey, 1966; Raven et al., 1979; Rothman et al., 1991). However, most of these studies have focused on work with the legs only when evaluating the effects on performance while wearing a respirator.

Although firefighting tasks include hiking with loads, much of the work involves strenuous upper body work such as stringing and pulling fire hose and constructing fire lines with a shovel or pulaski (Sharkey, Jukkala, Putnam, Tietz, 1980). Average fire fighting tasks require an oxygen uptake (VO_2) of approximately 22.5 mL/kg/min, with upper body tasks requiring more or less energy depending on the task: Pulaski work requires approximately 22.3 mL/kg/min; shovel work requires approximately 22.9 mL/kg/min; and other tools require between 20 to 30 mL/kg/min (Sharkey, 1977). Since workers cannot sustain more than 50% of their maximum aerobic capacity for an eight hour shift, the current fitness standard for firefighters used by the USFS is 45 mL/kg/min. This value accounts for the 50% drop in performance associated with long hours of work. Franklin, Vander, Wrisley, and Rubenfire (1983) determined that peak VO_2 during arm work is 80% of the VO_{2max} during leg work; peak work load is 55%, and minute ventilation ($\dot{V}_E$) is 84% of VO_{2max} for leg work. For the identical power output, arm exercise requires higher levels of VO_2, carbon dioxide output (CO_2), V_E, and heart rate (HR) than leg exercise (Casaburi, Barstow, Robinson, & Wasserman, 1992) Since respirators impose an additional physiological demand on a worker, in conjunction with upper body work, respirators may further compromise performance (Raven et al., 1979; Thompson & Sharkey, 1966). Therefore, the current fitness standards may have to be adjusted to reflect the demands of upper body work and respirator wear.

A recent study showed that the use of an air purifying respirator (resistance cartridges = 36 mm H_2O), while performing leg work on a treadmill, reduced VO_{2max} by 4.1 mL/kg/min or 16% (Townsend, Mead, & Sharkey, 1992). Since there appears to be little or no research available on work capacity while performing arm exercise and wearing a respirator, it may be beneficial to evaluate the physiological effects of using a respirator while performing sustained upper body exercise.

In addition, researchers have attempted to develop a simple test to screen firefighters who must wear respirators, but these tests have primarily used leg work to define work capacity (Raven et al., 1979, 1981; Townsend et al., 1992). The current tests for predicting a workers performance while using a respirator may need to be reevaluated since arm work at any given work load is performed at a greater oxygen cost, higher ventilation rate, heart rate, and perceived level of exertion than leg work. Ideally, a suitable test would be simple and quick to administer for large numbers of people, and be relatively inexpensive. It would also take into account the lung and chest wall mechanics as well as the respiratory muscle fatigue associated with sustained submaximal arm exercise and respirator resistance (Raven et al., 1979). The primary target for a predictive test has been the use of a single pulmonary function test such as the maximal voluntary ventilation (MVV), forced expiratory volume in one second ($FEV_{1.0}$), peak expired flow (PEF), and/or forced expiratory flow (FEF) (Raven et al., 1979).

VO_2 measurements along with various muscular fitness tests, a field test or both may be good predictors for screening firefighter applicants who must work under respirator constraints while performing strenuous arm work.

Muscular strength, as well as endurance, is a significant factor in the performance of wildland firefighting tasks. If people are not physically able to handle the rigors of an 8- to 14-hour day of fire fighting, they will fall behind in work production and jeopardize their safety and the safety of their co-workers. Muscular fitness scores are highly correlated to the tasks of wildland firefighters, and may be a means of predicting a persons work capacity while wearing a respirator (Sharkey et al., 1980).

Purpose of the Study

The purpose of this study was to determine the effects of wearing an APR on sustained upper body exercise--arm cranking specifically. This study looked at the physiological variables that are influenced during arm exercise while using an APR. These include VO_2, VCO_2, $\dot{V}_E$, HR and blood lactate concentrations. In addition, several pulmonary function tests, a battery of muscular fitness tests, and a field test were assessed for their ability to predict sustained arm performance while wearing an APR.

Significance of Problem

The study has provided additional information regarding respirator use and respiratory physiology during arm work. It also has provided additional information regarding the development of fitness standards for persons who are required to wear a respirator while performing prolonged submaximal work.

Delimitations

The delimitations of the study include the following:

1. The sample population was limited to 9 men and 9 women. All were healthy volunteers between 18 and 36 years of age.
2. There was no minimum fitness requirement for volunteer subjects.

Limitations

The limitations of the study include the following:

1. The level of motivation was not controlled in this study.
2. The health, nutrition, amount of stress, sleeping habits, and outside activities of the subjects were not controlled prior to or during the subjects' inclusion in the study.

Hypothesis

Each hypothesis was tested at the 0.05 level of significance.

1. There will be no significant difference between arm peak VO_2, $\dot{V}_E$ and HR with or without the respirator for the arm peak test.
2. There will be no significant difference between work in

watts for the 30-min endurance test with or without the respirator.

3. No individual measure of aerobic fitness, pulmonary function muscular fitness and/or field test will predict performance with the APR.

Definition of Terms

Arm ergometry, upper body work, and upper body exercise (UBE) are used interchangeably to refer to arm cranking on an arm ergometer performed without restriction to the torso.

Forced Expiratory $Flow_{25-75}$ (FEF_{25-75}) is the flow rate of air during the middle 50% of the forced vital capacity, expressed as L/min.

Forced Expiratory Volume in 1 Second ($FEV_{1.0}$) is the volume of air exhaled during the first second of the FVC.

Forced Vital Capacity (FVC) is the maximal forced expiration in liters following a maximal inspiration.

Maximal Oxygen Consumption (VO_{2max}) represents an individual's maximal capacity to consume oxygen. During incremental exercise, it is the point where the oxygen level plateaus and shows no further increase with increasing workload. It may be expressed in relative units (mL/kg/min) or absolute units (L/min).

Maximal Voluntary Ventilation (MVV) measures the maximal volume of air that a subject can exhale in a specified time. This study utilized a 12 second MVV.

Minute Ventilation ($\dot{V}_E$) represents the volume of air exhaled during one minute ($\dot{V}_E$ = breathing rate x tidal volume). It is expressed in L/min.

Peak Expired Flow (PEF) refers to the maximal flow rate achieved during a forced expiration (usually FVC).

Peak Inspiratory Flow (PIF) refers to the maximal flow rate achieved during a forced inspiration.

Ventilatory Threshold (VT) is the point where ventilation (L/min) increases disproportionately with VO_2.

Chapter Two

REVIEW OF LITERATURE

This section contains a review of literature relevant to the study. The review is subdivided into the following sections: (1) The physiological effects of arm ergometry, (2) The physiological effects of respiratory wear, and (3) Predictors of work performance while wearing a respirator and performing arm ergometry.

Physiological Effects of Arm Ergometry

Recent research has focused on upper body exercise in recognition that upper body muscle groups are used in a variety of occupations, including firefighting (Sawka, 1989). Since arm testing may be a better predictor of performance for those people whose usual physical activity is dominated by arm work, upper extremity testing may be a more appropriate means of evaluating functional capacity and in establishing target levels for exercise testing and training (Franklin et al., 1983).

Vokac, Bautz-Holter and Rodahl (1975) conducted a study of seven healthy men of average fitness to measure VO_2 and HR response between leg pedalling and arm cranking exercise --sitting and standing postures. This study demonstrated that the oxygen uptake/work load relationship was curvilinear for arm cranking. At approximately 250-300 kpm/min (or at an oxygen uptake of 0.8 - 0.9 L/min) oxygen uptake began to increase more rapidly for arm cranking while for leg pedaling the increase was more gradual. The rapid increase for arm cranking continued until maximal exertion was reached (work loads greater than 900 kpm/min), then oxygen uptake rose much less rapidly, while oxygen uptake for pedalling continued to rise in a rectilinear fashion. At maximum exertion, oxygen uptake was approximately 78% of the oxygen uptake for the legs. The same pattern was observed for the heart rate/work load relationship, with heart rate increasing much more rapidly for submaximal arm cranking compared to pedaling. Vokac et al. (1975) concluded that at maximal loads VO_2 was 15%-25% lower for arm cranking than for leg pedaling, but at submaximal workloads VO_2 and heart rate were significantly higher for arm cranking than for pedaling. He also concluded that mechanical efficiency decreased with increasing submaximal workloads, whereas mechanical efficiency remained the same with leg pedaling. When pulmonary ventilation was compared between arm cranking and pedaling, ventilation increased proportionately with VO_2 along the same ventilatory equivalent line ($V_E/VO_2 = 24$) and hyperventilation ($V_E/VO_2 > 40$) was seen at maximum levels only for pedaling. On the other hand, a relative hyperventilation was present at all submaximal workloads (V_E/VO_2 greater than 30) for arm cranking. The sharp increase in heart rate and pulmonary ventilation with arm cranking is possibly due to the slower response kinetics for arms than for legs. In addition, respiratory frequency--due to the attachment of the arms to the thorax--was influenced by the rhythmical movements of the extremities more easily in arm cranking than in pedaling. This synchronizing behavior, also referred to as entrainment, was seen primarily at 900 kpm/min where there was a 1:1 relationship between revolutions per minute and breaths per minute (50 rev/min to 50 breaths/min). At 600 kpm/min frequency was increased to 2:1 (two revolutions to every breath). There was no significant difference between arms and legs for rotation frequencies actually used at maximal efforts for arm cranking or pedaling.

In a study by Franklin et al. (1983), VO_2, $\dot{V}_E$, HR, rate of perceived exertion (RPE), and respiratory exchange ratio (VO_2/VCO_2) were also found to be greater during arm cranking than during leg pedaling at similar submaximal work loads. At work loads greater than 450 kpm/min, VO_2 and HR were significantly greater. The $\dot{V}_E$ and RPE were significantly larger at work loads greater than 300 kpm/min, and respiratory exchange ratio, although greater, was only significant at 600 kmp/min. For maximal work loads, arm cranking (675 kpm/min) was only 55% of maximal work loads for leg ergometry (1,230 kpm/min); and VO_{2max} during arm work (37 mL/kg/min) was 80% of the VO_{2max} during leg work (46 mL/kg/min).

Several researchers found that for the same power output, arm exercise requires higher VO_2, VCO_2, $\dot{V}_E$, and HR than leg exercises, and response kinetics are slower (Bevegard, Freyschuss & Strandell, 1966; Davies & Sargeant, 1974; Franklin et al., 1983; Stenberg, Astrand, Ekblom, Royce, & Saltin, 1967; Vokac et al., 1975; Casaburi et al., 1992) . The VO_2, VCO_2, and $\dot{V}_E$ were not statistically higher for arm exercise at lower power outputs; but at higher power outputs, where blood lactate starts to rise, VO_2, VCO_2, and $\dot{V}_E$ exceeded that of leg exercise. For each 1 mMol/L of rise in blood lactate there was an increase in VO_2 (0.09 L/min), VCO_2 (0.14 L/min), $\dot{V}_E$ (5.2 L/min) and HR (5.7 b/min). Therefore, Casaburi and associates (1992) suggest that it is the higher level of blood lactate at a given power output for arms that produce the differences in ventilatory and gas exchange responses.

Bevegard et al. (1966) studied circulatory adaptations to arm and leg exercise in supine and sitting positions. This study focused on the difference in circulatory response to exercise performed with relatively small muscle groups (arm work) verses larger muscle groups (leg work, combined arm and leg work). The results of this study showed that mechanical efficiency was less with arm work only, but during combined arm and leg work efficiency was the same as with leg exercise alone during more severe exercise. During arm exercise, $\dot{V}_E$ and HR increased significantly more in relation to oxygen uptake. Ventilation increases were associated with an increase in both breathing rate and tidal volume and with increased lactate concentration of arterial blood in response to higher workloads.

In 1989, Miles, Cox, and Bomze reviewed the cardiovascular responses to upper body exercise. Their research indicated that cardiac output (CO) for a given submaximal workload in arm versus leg ergometry is similar; for each liter increase in VO_2, CO increases by approximately 6 liters. During upper body exercise, though, the increase in cardiac output is accomplished by an increase in HR and a decrease in SV (Miles, Sawka, Hanpeter, Foster, Doerr & Frey, 1984, Miles et al., 1989; Sawka, Latzka, & Pandolf, 1989; Toner, Sawka, Levine, & Pandolf, 1983). Increased HR is associated with an increase in sympathetic stimulation during upper body exercise. The lower stroke volume (SV) may be due to the absence of the skeletal muscle pump in the lower extremities, leading to pooling of blood in the legs, a reduced venous return and ventricular end diastolic volume, and a decrease in contraction efficiency. Another limit to SV may be the increased afterload during upper body exercise (Miles et al., 1989; Bevegard et al., 1966). Systolic and diastolic blood pressures are increased in upper body exercise due to increased total peripheral resistance. Increased resistance is due to the increased isometric torso stabilization and grasping of the handcrank while performing UBE (Sawka, 1989;

Bevegard et al., 1966). Blood flow is also restricted by mechanical compression of the vasculature. When intramuscular pressure exceeds perfusion pressure, vascular resistance is increased and blood flow reduced (Sawka, 1989).

Physiological Effects of Respirator Wear

Research on the physiological effects of wearing a respirator has shown increase in breathing resistance, dead air space, heat stress, weight, and several cardiovascular stresses (Raven et al., 1979).

Breathing Resistance

Increases in breathing resistance, both inspiratory and expiratory, caused by the use of a respirator will result in a decrease in submaximal VO_2 and $\dot{V}_E$ and will contribute to a decreased time to exhaustion (Raven et al., 1979; Craig, Blevins, Cummings, 1970). An APR with clean new cartridges will have an increased inspiratory resistance ranging from 31 to 52 mm H_2O at a flow rate of 1.4 L/sec, and the expiratory resistance will range from 20-31 mm H_2O at the same flow rate (Louhevaara, 1984). In addition to breathing resistance, a respirator will increase dead space. The combination of increased resistance and dead space will result in increased tidal volume, decreased respiratory frequency, and decreases in alveolar ventilation (Gee, Burton, Vassallo, & Gregg, 1968; Raven et al, 1977). To maintain a set alveolar ventilation while wearing a respirator, $\dot{V}_E$ and overall work will increase. This increase in $\dot{V}_E$ occurs by increasing inspiratory pressure via the respiratory muscles (diaphragm, external and internal intercostals, scalenes, sternomastoid, and abdominal muscles). Increased resistance due to respirator wear will significantly increase work time to completion of a task at both maximal and submaximal levels (Raven et al., 1979). Craig et al. (1970) found that the mask alone, with cartridges removed, was enough to increase work time. With cartridges attached, work time increased approximately 21 to 27 percent.

Since there is a positive relationship between respirator filter resistance and the degree of dyspnea (breathlessness) a subject experiences, any change in filter resistance will affect a workers ability to sustain ventilation and ultimately decrease work performance (Lerman, Shefer, Epstein, & Keren, 1983). Therefore, when considering the use of a respirator, all factors concerning decreased work performance must be weighed against the amount of protection required to perform the work. Moreover, the increased stress to perform upper body work at a given workload (increased VO_2, $\dot{V}_E$, VCO_2, and HR) must be included when evaluating the effect on work performance and time to complete a task.

Heat Stress

Heat stress, especially in firefighting situations, poses a concern for respirator users. The relative humidity under a respirator may be as high as 90-100%. An added heat stress of 7.5^0C under a disposable respirator was seen in a study by Jones (1991). Since heat loss from the respiratory tract accounts for approximately 11% of the total heat loss from the body in a normal comfortable environment, the increased heat due to a hot environment and respirator use will limit evaporation and consequent cooling of the body. Heat stress will cause an increase in HR, an increase in breathing frequency, and a decrease in tidal volume (hyperventilation) in an attempt to dissipate heat. Heat stress may also cause an increased perception of breathing difficulty, an increase in feelings of claustrophobia, and decrements of both mental and manual performance (Jones, 1991; Raven et al., 1979).

Cardiovascular Responses

There have been a variety of findings regarding the effect of respirator wear on HR. Some researchers reported minimal effects on HR while others reported a modest increase in HR while performing leg work (Jones, 1991). Increases in HR while wearing a respirator may be due to an increase in cardiac demand. The Increased cardiac demand may be due to several factors, including the increased work of breathing, increased heat stress, increased chemoreceptor or baroreceptor activity caused by the changes in alveolar ventilation and intrathoracic pressure (Hermansen, Vokac, Lereim, 1972; Jones, 1991), and anxiety related to dyspnea (Raven et al., 1979). No studies were found that determined the effects of upper body work on HR while wearing a respirator.

Blood pressure (BP) was found to increase at higher work loads when respirators were used. Spioch, Kolza and Rump (1962) tested subjects while performing the Harvard step test and found a 24% increase in recovery systolic BP associated with respirator usage. In addition, Jones (1991) found two subjects (n = 10) who had clinically significant changes in BP while performing treadmill exercise at a heavy work load (between 51% and 75% of VO_{2max}). In one case, the systolic pressure averaged 196 mmHg during the heavy exercise session without the disposable respirator and rose to 228 mmHg in a similar work session with the respirator. The second subject experienced an increase in diastolic pressure from 81 mmHg without the respirator to 96 mmHg with the respirator during heavy work levels. Only a few studies have evaluated blood pressures while wearing a respirator, and no studies were found using upper body work and respirators.

Predictors of Work Performance While Wearing a Respirator

Several studies have been conducted in an attempt to formulate a test that could predict a worker's ability to perform while wearing a respirator. Since the primary effect of a respirator is an increase in inspiratory and expiratory resistance, flow measurements appear to be good predictors of work performance while wearing a respirator. Raven et al. (1981; 1979) evaluated pulmonary function measures in males and females while performing treadmill tests to predict performance time on maximal and endurance-type exercise tests. They found that the respirator mask reduced pulmonary function measures from 7-15%. Mask resistance reduced FVC by approximately 11.6% (0.65L); $FEV_{1.0}$ by 7.3% (0.33L); and $MVV_{.25}$ by 7.4% (12.4 L/min). A linear regression of the above data determined that the $MVV_{.25}$ was the best predictor of maximal exercise performance with and without the respirator. This is significant because $MVV_{.25}$ is a test of lung function that is easy to administer and reflects lung and chest wall mechanics as well as respiratory muscle fatigue. The $MVV_{.25}$ relates well to the 4-min MVV assessment of respiratory muscle fatigue (Freedman, 1970), sustained maximal exercise ventilation, and respirator resistance. Freedman (1970) determined that a person could sustain 50% of their $MVV_{.25}$ for an indefinite length of time. Raven et al. (1981) formulated an equation to predict the effects of breathing resistance on $MVV_{.25}$ while wearing a respirator that has a predictive value of 70%.

$$\text{Mask } MVV_{.25} = MVV_{.25} \times 0.49 + 28.9$$

If work is to be prolonged (greater than 1 hour) a ventilatory creep of 20 to 30 L/min must be added to the above formula (Tenney and Reese, 1968) when determining ventilatory requirements of the job. Additional studies by Townsend (1991) and Mead (1991) used treadmill and endurance walks to determine the effects of wearing a respirator on work performance. These studies further confirmed that $MVV_{.25}$ along with the ventilatory requirements of a job could be used to determine if a worker has the pulmonary capacity to do the work. Townsend (1991) specifically focused on women and found that $MVV_{.25}$ along with weight and body size were predictors of work performance while wearing a respirator. All of the above studies evaluated work performance using leg work. No studies were found that attempted to predict sustained arm work while wearing an APR. Since arm work at a given work load increases ventilatory requirements it may add to the problem associated with respirator wear and impose additional demands on ventilation.

Chapter Three

METHODOLOGY

Subjects

This study utilized nine male and nine female subjects between the ages of 20 and 36. Subjects were not required to meet a minimum fitness standard but were screened to insure they were healthy volunteers (Appendix B). The screening included a medical questionnaire, blood pressure, and sitting pulse checks. In addition, all subjects read and signed an informed consent form (Appendix A). The subjects were students recruited from The University of Montana activity courses, and employees from the U.S. Forest Service. All subjects performed a battery of tests which included: pulmonary function tests, peak oxygen consumption arm ergometry tests with and without a respirator, 30-minute arm ergometry tests with and without a respirator, muscular fitness tests, a graded maximal oxygen consumption test (VO_{2max}) on the treadmill, and a 4.83 km (3 mile) field (pack) test while wearing a 20.5 kg (45 lb) pack. Each subject was required to return for testing on seven separate days, with approximately one week between testing days.

Procedures

Day 1: Pulmonary Function, Bench Stepping, and Muscular Fitness Tests

The first day of testing included a series of pulmonary function tests using a Mustispiro computerized spirometry system. The spirometer was calibrated using a known volume (3 liters) and subjects wore a nose clip while the test was administered. A maximal one-breath inhalation and exhalation was used to determine FVC, $FEV_{1.0}$, PIF, PEF, and FEF_{25-75}. The MVV was measured by having subjects inspire and expire as forcefully and as quickly as possible for 12 seconds ($MVV_{.20}$). All pulmonary function test volumes were converted and reported in BTPS.

Testing on this day also included a submaximal exercise test, which consisted of bench stepping (height = 40 cm for men and 33 cm for women) at a pace of 22.5 steps per minute for 5 minutes. This test is used to predict VO_{2max} and is the current standard for predicting a firefighter's work capacity. Upon completion of the test the subject sat down and a 15 second pulse was taken. A blood sample for lactate analysis was taken, 45 seconds post test, by the finger stick method. Approximately 0.25 ml of blood was used for lactate analyses. The blood was mixed with 50 mL of lactate cocktail (1:2 dilution). This cocktail consisted of 400 micrograms NaF, 500 ml YSI buffer and 0.5 mL Triton X, and is used to lyse erythrocytes and inhibit glycolysis. The blood and cocktail was then analyzed by a YSI 2300 STAT Glucose/L-Lactate Analyzer. The researchers were gloved, and disposable lancets and capillary tubes were used as a precaution against blood contamination for subjects and researchers.

Subjects also performed a series of muscular fitness tests in the following order: absolute number of pull-ups, one repetition of maximum weight lifted (1-RM) leg press, absolute number of push-ups in 60 seconds, absolute number of sit-ups in 60 seconds, a 1-RM bench press, and a 1-RM arm curl. Instruction was given in safe lifting procedures before a maximum lift was attempted. Subjects then warmed up with a light weight (approximately 40% to 60% of perceived maximum) for 10 to 20 repetitions. After a rest of approximately one minute, the subjects switched to a medium weight (approximately 60% to 80% of perceived maximum) for 10 repetitions. After another minute of rest subjects attempted a maximum lift. Additional weight was added to the weight stack until the subject could no longer lift it. This usually occurred within three to four tries. The amount of weight lifted for the maximum lift was based on the subjects familiarity with lifting and through several trial attempts at maximum weight. After each attempt for a maximum lift, the subjects rested for one to two minutes before attempting another maximum lift. When the subject finished each test, a four minute rest was taken before beginning the next test.

Testing with the weight equipment was done at The University of Montana Athletic Department weight training room.

Pull-ups (absolute): Subjects warmed up with 10 to 20 repetitions of a light weight on the lat pull-down machine. Subjects then proceeded to the pull-up bar and did as many pull-ups as they could with palms facing toward the subjects' face (there was no time limit). A complete pull-up began with arms fully extended and ended when the chin was pulled up over the bar. The pull-up was not counted if there was excessive piking or swinging to aid the subject. The score was the total number of pull-us completed.

1-RM Leg press: From a seated position with legs flexed at a ninety degree angle the subjects pressed their leg forwards to full extension.

Push-ups (1 min): Subjects performed military style pushups without bending at the waist, knees off the floor, arms straight and hands beneath the shoulders. Subjects lowered body until the chest touched the test administrators fist then pushed up to a straight-arm position. Only those push-ups that were completed with good form were counted for the total score in one minute.

Sit-ups (1 min): Subjects laid on the floor with knees at approximately a 90-degree angle and fingers laced behind their neck. A complete sit-up began with a curl up from the waist and finished when the elbows touched the knees. A test administrator held the subjects feet for the one minute duration. The score is the total number of situps in 60 seconds.

1-RM Bench press: From a prone position the subjects pressed upward on the universal bench press until arms were fully extended.

1-RM Arm curl: From a standing position subjects grasped the cable arm curl bar with palms facing toward their body. The arm-curl began with arms fulling extended and ended when elbows were fully flexed. Subjects were not allowed to use their legs, torso, or back to assist in the curl motion and were required to keep their elbows at their sides throughout the entire motion.

<u>Day 2 and 3: Two 30-minute Arm Ergometry Tests With and Without the Respirator</u>

The second and third day of testing included two submaximal arm endurance tests one while wearing the APR and one without. The tests were conducted on a Bodyguard 900 Upper Body Exerciser and involved arm cranking for 30 minutes while maintaining a HR of 150 b/min. The subjects remained seated throughout the entire test and were encouraged not to use their legs. The order of respirator wear was random and on the subsequent day subjects performed the same test with or without the respirator, depending on the results of the random draw the first day. The respirator mask was a half-faced MSA device that strapped over the head with a multiple strap yoke. The mask has a lower set of straps that secure around the back of the neck to ensure a good seal at the chin. The mask meets the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) specifications for respirators. During the study, the mask was equipped with two combination HEPA-OV/AG cartridges--36mm H_2O resistance at 42.5 L/min. These filters are high efficiency particulate filters (HEPA) that have been approved for respiratory protection against organic vapors, chlorine, hydrogen chloride, sulfur dioxide, chlorine dioxide, dust, fumes, mists, and asbestos containing dusts. The arm endurance test began after a five minute warmup. Workload, via resistance or revolutions, was increased until a heart rate of 150 b/min was attained. Once the subjects' heart rate reached 150 b/min, the test began. Resistance was adjusted so that a heart rate of 150 b/min was maintained for 30 minutes. Subjects maintained an rpm of 60 visually by watching a cadence monitor, or by listening to a metronome set at 60 b/mins. Work rate (watts) and level of perceived exertion (RPE) were recorded every two minutes. Subjects indicated their level of perceived exertion by responding to a perceived exertion scale (Borg & Noble, 1974; Appendix C). The value of 1 indicated little or no exertion, while 10 indicated extreme exertion. A blood sample for lactate was taken by the finger stick method 45 seconds post test.

Day 4 and 5: Two Arm Peak VO_2 Tests With and Without the Respirator

On the fourth and fifth day, subjects performed two peak VO_2 tests for the arms--one while wearing a respirator and one without. The tests were conducted on a Bodyguard 900 Upper Body Exerciser. After a one to two minute warm-up, the test began. The initial work load was set at 25 watts with subjects arm cranking at 60 rpm. Subjects maintained rpm visually by watching the cadence monitor. One subject, F10, began at a work load of 12 watts/60 rpm due to limited arm strength. Wattage was increased in either 12.5 or 25 watt increments every one to two minutes, depending on the subjects' fitness/activity level. Most subjects reached maximal exercise in 6-8 minutes. During the last minute of exercise, subjects were encouraged to "go all out" with the maximum rpm that could be achieved. The test continued until the work rate could not be maintained. A peak VO_2 assessment was made when the subject had an respiratory quotient (R-value) greater than 1, a heart rate plateau, volitional fatigue, or a plateau in VO_2 and $\dot{V}_E$. Expired gases were collected using a Beckman metabolic measurement cart, which was calibrated with known gas concentrations before each test. Measurements obtained from this test included VO_2 (mL/kg/min), VO_2 (L/min), $\dot{V}_E$ (L/min), VCO_2 (L/min), and respiratory exchange ratio. Heart rate was monitored by a telemeter (CIC heart watch) and recorded each minute. A blood sample for lactate analysis was drawn 45 seconds post test by the finger stick method.

Day 6: Maximum Graded Exercise Test Without the Respirator

On the sixth day, each subject performed a maximum graded oxygen consumption test on a treadmill. The Montana Max protocol was used to achieve maximal O_2 values. This protocol is described by Sharkey (1990). Subjects walked or ran on a Quinton motorized treadmill, depending on their fitness, personal preference, and their usual exercise mode. Subjects began the test at approximately 70% of VO_{2max}. This was predetermined by their warm-up heart rate and step test values. Speed and grade were increased every 1-2 minutes based on the subjects' fitness/activity level. Subjects continued to exercise until volitional fatigue and/or maximum oxygen consumption was attained. A maximal VO_2 assessment was made based on the same criteria as the arm cranking peak test. Gas analysis was assessed the same as day four and five, and HR was recorded every minute. Each subject was given verbal instruction as to the test procedures, including instructions that they could terminate the test at any time. Forty-five seconds after the test, subjects had a venous sample of blood taken by finger stick method and blood lactates were analyzed.

Day 7: Field (Pack) Test

On the seventh day of testing, subjects were fitted with a 20.5 kg (45 lb) pack designed for carrying water.

Subjects were instructed to walk a 4.83 km (3 mile) flat, dirt course as fast as they could without running. At the end of the 3 miles, total time to finish, radial pulse, and a 45 second post test finger stick for blood lactate was taken and recorded.

All of the tests (with the exception of the strength measurements and the field test) were conducted in the Human Performance Laboratory at The University of Montana.

Analysis of Data

Descriptive statistics were used to determine the mean, standard deviation, and range of all independent and dependent variables.

The data were analyzed to compare variables measured with and without the respirator, using the paired student *t*-tests. The VO_2, $\dot{V}_E$, ventilatory threshold (VT), HR, lactate concentration, and work rate means were tested to determine if a significant difference existed between means for data collected with and without the APR while performing arm work. The acceptable level of significance was $p<0.05$.

The Pearson Product Moment Correlation coefficients (r) were used to determine the relationship among pulmonary function, muscular fitness, height, weight, max VO_2, peak VO_2 (with and without the APR), the field test, and performance on the 30-minute arm endurance test with the APR. Those variables that showed significant correlation (n=18, $p<.05$ = .4555, $p<.01$ = .5751; n=9, $p<.05$ = .6319, $p<.01$ = .7646) were used in a multiple and step-wise regression to determine which variable(s) predicted the effect of the APR on sustained arm work.

All statistics were done at The Forest Service Missoula Technology and Development Center (MTDC) using the StatView statistical program on the Macintosh II C1 computer.

Chapter Four

RESULTS

This chapter contains an analysis of the data collected from all 18 subjects and includes: the 30-minute arm ergometry tests (with and without the APR), the peak VO_2 arm ergometry tests (with and without the APR), the maximal graded exercise tests--treadmill, the pulmonary function tests, the muscular fitness tests, and the field (pack) tests.

Since males and females work as firefighters and since selection procedures must serve all applicants, it is necessary to present the data as pooled male-female (M-F) data. Reporting this way often gave a large range in various scores. Therefore, due to variations in weight, physical fitness, and experience between male and female subjects, data are also presented separately--male (M) and female (F).

The physical characteristics (age, height, and weight) for the combined M-F group (n=18), male (n=9) and female (n=9) group are in Table 1. See Appendix D for individual data.

TABLE 1: PHYSICAL CHARACTERISTICS--MEANS AND SD

GROUP	AGE (yrs)	HEIGHT (in)	WEIGHT (lbs)
M-F COMB	24.9 ±4.6	67.3 ±8.6	157.8 ±36.6
MALES	24.3 ±4.7	70.1 ±3.2	184.2 ±33.8
FEMALES	25.6 ±4.6	65.0 ±1.3	131.3 ±11.5

M-F Comb = male and female combined data

30-Min Arm Ergometry Tests

The mean differences were not statistically significant for the M-F combined, male or female group (3.15 watts, 3.00 watts and 3.30 watts) between the two trials with and without the APR for the 30-min arm ergometer test. Although there was no statistical significance, there was a consistent decrease in work output with the respirator (5.6%, 4.02%, and a 8.3% respectively). The mean work rate was extracted from the last 10 minutes of the test and is an average measure of work in watts. There was no significant difference between lactate values with and without the APR. See Table 2 for the means and SD between the three groups and Table 3 for the *p*-values.

TABLE 2: 30-MINUTE ARM ERGOMETRY TEST--MEANS AND SD

VARIABLE	M-F COMB	MALES	FEMALES
WORK W (watts)	54.0 ±27.2	71.7 ±18.1	36.4 ±23.2
WORK W/O (watts)	57.2 ±27.7	74.7 ±20.8	39.7 ±22.6
LA W (mM/L)	3.2 ±1.8	4.0 ±2.1	2.4 ±.89
LA W/O (mM/L)	3.2 ±1.1	3.8 ±1.2	2.7 ±.77

W = with the APR; W/O = without the APR

TABLE 3: 30-MINUTE ARM ERGOMETRY TEST--*p*-VALUES

W vs W/O	*p*-(M-F)	*p*-MALES	*p*-FEMALES
WORK (watts)	0.0705	0.1932	0.2436
LA (mM/L)	0.9839	0.6730	0.2484

* significant values $p=<0.05$
W = with the APR; W/O = without the APR

Arm Peak VO2 Tests--Arm Ergometer

The arm peak-test lasted approximately 6-8 minutes for most subjects. Max values were assessed by a respiratory quotient value greater than one, a plateau of heart rate, volitional fatigue, or plateau in VO_2 and V_E. The values that were recorded and tested for significance with and without the APR included VO_2, V_E, ventilatory threshold (VT), max HR, and lactate values (LA).

The mean difference in VO_2 for the peak-test with and without the APR--M-F combined (2.239 mL/kg/min and .156 L/min) was statistically significant and represents a 6.77% and 8.30% decrease respectively in peak values with the respirator. The mean difference for females was also significant (2.167 mL/kg/min and .164 L/min). These values represent a 7.4% and 11.0% decrease in VO_2 with the APR. For the male group, there was no significant difference with and without the respirator (Table 5, 6, and 7).

Absolute and relative units will be used when describing maximal aerobic power. Absolute maximal aerobic power reflects the ability to perform external work or work that is body supported (seated arm ergometry). Relative maximum aerobic power is more appropriate when body mass must be carried during the work (ACSM, 1991; Docherty, McFadyen, & Sleivert, 1992). Since this study incorporated tests that are weight bearing (treadmill and pack test--weight bearing with external loads carried) and non-weight bearing tests (arm ergometry), maximal oxygen uptake is expressed as both absolute (L/min) and weight-relative units (mL/kg/min).

The mean difference in minute ventilation with and without the APR was significant ($p<.01$) for all three groups--M-F combined, male, and female (19.08 L/min, 23.67 L/min, and 15.78 L/min). The mean differences represent a decrease in ventilation of 18.9%, 18.0%, and 15.78%

respectively. These values are consistent with a recent study by Townsend (1991).

The mean differences between ventilatory threshold (VT) with and without the APR were not significant. The VT for the arm peak test with and without the respirator was plotted using the ventilatory equivalent for the O_2 uptake (VE/VO_2) as described by Caiozzo, Davis, Elllis, Azus, Vandagriff, Prietto, & McMaster (1982).

The mean differences between Max HR values for the M-F combined group and the female group (2.28 b/min, and 4.67 b/min) were significant and reflects a 1.2% and a 1.6% decrease with the APR. The mean difference for the male group was not significant.

There was no significant difference for lactate values with and without the APR for the arm peak tests (See Table 4 and 6).

TABLE 4: ARM PEAK TEST--MEANS and SD

VARIABLE	M-F COMB	MALES	FEMALES
VO_2 W (mL/kg/min)	30.9 ±6.6	34.2 ±5.5	27.4 ±6.1
VO_2 W/O (mL/kg/min)	33.1 ±7.4	36.5 ±7.9	29.6 ±5.2
VO_2 W (L/min)	2.2 ±.78	2.8 ±.56	1.6 ±.41
VO_2 W/O (L/min)	2.4 ±.80	3.0 ±.62	1.8 ±.44
$\dot{V}_E$ W (L/min)	87.6 ±23.66	107.5 ±14.8	68.3 ±9.6
$\dot{V}_E$ W/O (L/min)	107.2 ±31.92	131.5 ±26.5	84.1 ±14.8
VT W-VO_2 (mL/kg/min)	16.2 ±4.1	18.0 ±3.7	14.4 ±3.8
VT W/O-VO_2 (mL/kg/min)	15.6 ±3.5	17.6 ±3.0	13.6 ±2.8
VT W-VE (L/min)	37.4 ±13.6	44.7 ±13.2	30.2 ±10.0
VT W/O-VE (L/min)	38.4 ±11.2	46.2 ±8.1	30.6 ±8.0
HR MAX W (b/min)	176.0 ±13.62	177.0 ±9.3	176.0 ±16.7
HR MAX W/O (b/min)	179.0 ±9.97	177.0 ±10.2	180.0 ±11.9
LA W (mM/L)	8.6 ±1.9	10.2 ±1.9	7.3 ±.9
LA W/O (mM/L)	8.7 ±2.1	10.0 ±1.6	7.2 ±1.2

W = with APR; W/O = without APR

TABLE 5: ARM PEAK TEST--PERCENT CHANGE W & W/O THE APR

VARIABLE W vs W/O	M-F COMB	MALES	FEMALES
VO_2 (mL/kg/min)	-6.77%	-6.3%	-7.4%
VO_2 (L/min)	-8.30%	-6.7%	-11.0%
V_E (L/min)	-18.9%	-18.0%	-15.78%
VT--VO_2 (mL/kg/min)	+3.8%	+2.3%	+5.9%
VT--VE (L/min)	-2.6%	-3.2%	-1.3%
HR MAX (b/min)	-1.2%	-0.0%	-1.6%
LA (mM/L)	-1.1%	+2.0%	+1.4%
30-MIN ARM ERGOMETRY TEST			
WATTS	- 5.6%	-4.02%	-8.3%

W = with APR; W/O = without APR

TABLE 6: ARM PEAK TEST--p-VALUES

VARIABLE W vs W/O	p-M-F COMB	p-MALES	p-FEMALES
VO_2 (mL/kg/min)	0.0343*	0.2324	0.0438*
VO_2 (L/min)	0.0441*	0.2907	0.0470*
$\dot{V}_E$ (L/min)	0.001*	0.0018*	0.0062*
VT--VO_2 (mL/kg/min)	0.4671	0.7703	0.3331
VT--VE (L/min)	0.7025	0.7149	0.9011
HR MAX (b/m)	0.0405*	0.1932	0.0970
LA (mM/L)	0.6619	0.7267	0.8103

* significant values p=< 0.05; W = with APR; W/O = without APR

Maximum Graded Exercise Test--Treadmill

The mean VO_{2max} scores for the M-F combined, the male, and the female group were 46.4 mL/kg/min, 49.4 mL/kg/min, and 43.4 mL/kg/min respectively. Since 45 mL/kg/min is the required fitness level for firefighters, this group was within the range for applicants for wildland firefighters. Although the female group was below the VO_2 standard for firefighters, there was no significant difference found between the male and female group (p = .0845) when compared using an unpaired t-test for the grouping variable--gender versus VO_2 (mL/kg/min).

The VT for the leg max test was plotted using the same calculations as described for the arm peak test. See Table 7 for the treadmill test values.

TABLE 7: TREADMILL TEST--MEANS AND SD

VARIABLE	M-F COMB	MALES	FEMALES
VO_2 (mL/kg/min)	46.4 ±7.4	49.4 ±7.9	43.4 ±5.7
VO_2 (L/min)	3.3 ±7.4	4.1 ±0.6	2.6 ±0.5
VT (mL/kg/min)	36.4 ±8.0	37.8 ±9.8	35.0 ±6.0
LA (mM/l)	9.5 ±3.2	10.9 ±3.2	8.0 ±2.6
HR (b/min)	187.0 ±8.8	186.7 ±9.4	188.0 ±9.3

Pulmonary Function Tests

Other studies show that resistance to both inspiration and expiration by a respirator reduces pulmonary function when subjects are tested on a treadmill. In addition, several pulmonary function measures have been predictive of performance with an APR. Therefore, various pulmonary function tests were included to determine if a relationship exists between these tests and sustained submaximal arm work. Males generally have greater volumes for pulmonary function due to their greater size, and this was true for this study. All the pulmonary function tests, except the $FEF_{.25-.75}$ were significantly correlated with sustained arm work for the M-F combined group ($MVV_{.20}$, $FEV_{1.0}$, and FVC = $p<.01$; PIF and PEF = $p<.05$). The only correlation that showed significance for the male or female group was PIF for the male group ($p<.05$). See Table 8 and Table 11.

TABLE 8: PULMONARY FUNCTION MEASURES--MEANS AND SD

VARIABLE	M-F COMB	MALE	FEMALES
FVC (L)	4.6 ±1.1	5.5 ±.48	3.7 ±.64
$FEV_{1.0}$ (L)	4.0 ±0.9	4.7 ±.60	3.4 ±.35
PIF (L/s)	6.7 ±1.7	7.5 ±1.6	5.8 ±1.4
PEF (L/s)	9.3 ±2.6	10.9 ±2.5	7.7 ±1.6
FEF_{25-75} (L/s)	4.6 ±1.5	5.2 ±1.9	4.0 ±.69
$MVV_{.20}$ (L/min)	156.7 ±32.5	182.3 ±22.7	131.0 ±15.0

Muscular Fitness Tests

Firefighters often haul heavy loads and work long hours digging fire line. These tasks require a person to be physically fit to meet the demands of the job. Muscular fitness is an integral part of total fitness for work capacity. It depends on both muscular strength and endurance. Therefore, muscular fitness tests were used to evaluate the correlation between these tests and sustained upper body work. The large variance between the scores for the M-F combined group can generally be attributed to the differences between the size and weight of males and females. Males and females tend to have large differences between cross sectional area of muscle, a main determinant for strength, and this study found significant differences (unpaired _t_-Test for gender vs strength tests) between males and females for the bench press ($p < .0001$), pull-ups ($p = .0047$), leg press ($p < .0001$), and arm curl ($p < .0001$). Push-ups and sit-ups showed no significant differences between males and females.

The leg press, bench press and arm curl for the M-F combined group correlated ($p<.01$) to arm endurance with the APR. The bench press and arm curl correlated ($p<.05$) to arm endurance with the APR for the female group, and none of the muscular fitness scores correlated to arm endurance with the APR for the male group. See Table 9 for the means and standard deviations and Table 10 for the significant correlations.

TABLE 9: MUSCULAR FITNESS--MEANS AND SD

VARIABLE	M-F COMB	MALE	FEMALE
SIT-UPS (#/min)	41.1 ±10.0	43.1 ±11.5	39.1 ±8.3
PUSH-UPS (#/min)	37.0 ±18.2	44.8 ±16.9	29.0 ±16.7
PULL-UPS (abs #)	7.3 ±6.1	11.0 ±6.0	3.5 ±3.3
LEG PRESS (1-RM)	398.9 ±104.6	484.4 ±58.3	313.3 ±58.2
BENCH PRESS (1-RM)	118.3 ±47.6	156.7 ±33.4	80.0 ±19.8
ARM CURLS (1-RM)	70.6 ±31.0	95.6 ±23.6	45.6 ±8.8

#/min = total number performed in one minute; abs # = absolute number performed; 1-RM = maximum weight lifted for one repetition

Field (Pack) Tests

Muscular fitness measures between males and females were significantly different. However, the difference was not significant for the Pack Test between males and females (p = .0590). The pack test was measured in seconds to complete the three mile course. This test was significantly related to the step test (-.455), the leg VO_{2max} (-.592), the strength tests, including leg press (-.553) and pull-ups (-.501). In addition, the Pack Test was correlated to the arm peak VO_2 (-.520), the arm VT (-.592), and the sustained arm endurance test (-.707). The pack test along with the leg max test yielded the strongest predictive value of sustained arm endurance with the APR when a step-wise regression was used (R = .902; R^2 = .813). See Tables 10, 11, and 12.

TABLE 10: FIELD (PACK) TEST--MEANS AND SD

VARIABLE	M-F COMB	MALE	FEMALE
TIME (sec)	2547.8 ±326.4	2404.1 ±260.0	2692.0 ±335.1
LA (mMol)	2.9 ±1.7	3.4 ±2.1	2.4 ±1.3

Correlations

Pearson Product Moment Correlation coefficients (r) were used to determine the relationship between the various tests and performances on the 30-minute arm ergometry test with the APR. Significant correlations indicated that a relationship is more likely to be real and not due to chance; however they do not imply cause and effect. Significant correlations are summarized in Table 11; variables that were not significant for any group were omitted. The significant correlations were then used to calculate a multiple and step-wise regression to determine which measures could be used to predict sustained submaximal arm work with an APR (Table 12).

TABLE 11: CORRELATIONS BETWEEN SELECTED VARIABLES AND PERFORMANCE ON THE 30-MIN ARM ERGOMETRY TEST

ARM ENDURANCE W	r (M-F)	r (M)	r (F)
HEIGHT (in)	.789	---	---
WEIGHT (lbs)	.732	.744	---
$MVV_{.20}$ (L/min)	.554	---	---
PIF (L/s)	.560	.700	---
PEF (L/s)	.541	---	---
$FEV_{1.0}$ (L)	.730	---	---
FVC (L)	.729	---	---
LEG PRESS (1-RM)	.682	---	---
BENCH PRESS (1-RM)	.688	---	.739
ARM CURL (1-RM)	.663	---	.631
FIELD TEST (sec)	-.709	---	-.641
LEG MAX (L/min)	.813	---	.725
ARM PK W/O (mL/kg/min)	.542	---	.858
ARM PK W (mL/kg/min)	.597	---	.685
ARM PK W/O (L/min)	.781	---	.821
ARM PK W (L/min)	.809	---	.773
ARM PK MAX V_E W (L/min)	---	.728	---
ARM PK MAX HR W/O (b/min)	---	---	-.747
ARM PK MAX HR W (b/min)	---	.673	-.727
LA LEG MAX (mL/kg/min)	---	-.720	---
VT TM VE (L/min)	.550	---	---
VT APK W VO_2 (mL/kg/min)	.654	---	.639
VT APK W/O VO_2 (mL/kg/min)	.574	---	.825
VT APK W VE (L/min)	.652	---	---
VT APK W/O VE (L/min)	.763	---	.570

n = 18, df = 17; p(.05) = .4555; p(.01) = .5751
n = 9, df = 8; p(.05) = .6319; p(.01) = .7646;
W = with APR; W/O = without APR

Regression Summary

Multiple linear regression was utilized to determine the best predictor or group of predictors for arm work while wearing a respirator. For the M-F combined group data, there were several combinations of tests that were predictive of performance. The best prediction of arm endurance from the pulmonary function tests were $FEV_{1.0}$ and FVC (R = .747; R^2 = .549). The best predictors of arm endurance among the strength tests were the bench press and arm curl (R=.694; R^2=.482). Adding the field test strengthened this prediction (R=.857; R^2=.735). The field test alone had an r=.708; r^2=.501.

Finally, a computer generated step-wise regression was run to see which tests were predictive of performance on the 30-minute arm ergometry test with the APR. The step-wise regression included the pulmonary function tests, the arm peak tests with and without the APR (L/min), the VO_{2max} treadmill test (L/min), the field test, leg press, bench press, arm curl, height, and weight. For the M-F combined group, the leg max (L/min) and the field test had a prediction of R=.864; R^2 .747. The leg max (L/min and mL/kg/min) and the field test yielded an R of .902; R^2 = .814.

Significant correlations were also evaluated using a computer generated step-wise regression for the separate male and female groups. The regression was run to find the best predictors of performance on the 30-minute arm ergometry test with the APR. The combination of the Arm Peak Max $\dot{V}_E$ (L/min) and the Arm Peak Max HR, both with the APR, yielded an $\underline{R}$=.856 and $\underline{R}^2$=.732 for the male group (See Table 12). The only test that emerged from the step-wise regression for the female group was the Arm Peak VO_2 without the APR ($\underline{r}$=.858; $\underline{r}^2$=.736; Table 11).

TABLE 12: MULTIPLE LINEAR REGRESSION

ARM ENDURANCE W-APR VS:		
M-F COMB		
	R	**R^2**
$FEV_{1.0}$ (L) FIELD TEST (sec)	0.832	0.692
BENCH PRESS (1-RM) ARM CURL (1-RM)	0.694	0.482
FIELD TEST (sec) LEG MAX (L/min)	0.864	0.747
FIELD TEST (sec) LEG MAX (L/min) LEG MAX (mL/kg/min)	0.902	0.814
MALES		
ARM PEAK MAX V_E W (L/min) ARM PEAK MAX HR W	0.856	0.732
FEMALES		
ARM PEAK W/O (mL/kg/min)	0.858	0.736

Chapter Five

DISCUSSION

The Effects of Respirator Wear

The primary purpose of this study was to assess the effects on performance of upper body exercise while wearing a respirator. This was achieved by evaluating the changes in workload that occurred over a prolonged period of time while arm cranking and maintaining a heart rate of 150 b/min, with and without the APR; and, by evaluating the physiological variables that were affected with and without the APR during an arm peak test.

30-Minute Arm Ergometry Tests

A 30-minute arm ergometry test was used to assess an individual's ability to sustain arm work at a heart rate of 150 b/min. There was a 5.6%, 4.02%, and 8.3% decrease in performance (watts) while wearing the APR for the M-F combined, male, and female groups. The difference between the means were not significant for any of the three groups (Table 3). There was a large standard deviation for the endurance trials for the M-F combined group (27.695 with and 27.156 without). The large range between subjects, due to gender, weight, and physical fitness of subjects in the study, may have contributed to the increased variability (see Table 1). The stronger subjects--both male and female--

seemed to work harder (higher watts) initially to get their heart rates to 150 b/min, while the less strong subjects had elevated heart rates at very low watts. Therefore, this may be where part of the great variation occurred for final power output between individual subjects. For example, one female subject had the lowest score of 9.0 watts with the APR and 7.5 without, and a male subject had the highest score of 96.0 watts with and 111.6 watts without the APR. In addition, it took all subject almost 10 minutes before they were able to reach a steady state of 150 b/min while arm cranking. This is consistent with a study by Vokac et al. (1975) that found heart rates to rise steeply and steadily during the first 6 to 8 minutes of exercise before a steady state was maintained. Another factor to consider with and without the APR may be the effect of entrainment or the rhythmical breathing that becomes synchronized with locomotor movements including arm cranking. Studies have documented entrainment occurring in subjects while walking, running, cycling, and arm cranking--especially when pedal frequency was paced with a metronome--but it doesn't seem to be a consistent phenomena associated with all subjects (Bechbache & Duffin, 1977; Jasinskas, Wilson, & Hoare, 1980; Vokac et al., 1975). Therefore, it may be possible that certain subjects were more entrained and maintained a more closely linked rhythmical breath rate and work load regardless of the respirator.

Although statistical significance was not achieved, there does seem to be some practical significance related to decreased work with the respirator. As stated earlier, workers cannot sustain more than 50% of their maximum aerobic capacity for an eight hour shift. Upper body firefighting tasks require approximately 22.3 to 22.9 mL/kg/min (Sharkey, 1977) or 2.1 L/min (HR 154 b/min) for low intensity work and 2.4 L/min (HR 172 b/min) for high intensity work (Docherty, 1992). The subjects from this study performed at 150 b/min or approximately equal to the 2.4 L/min established by Docherty in 1992. When one considers the decrement associated with respirator use (5.6%), ventilatory drift during sustained exercise (Dempsey, Vidruk, & Mitchell, 1985), and other factors such as heat and altitude, the practical significance may be more important. For instance, Townsend (1991) showed that smaller women who were in excellent physical shape (VO_2 50.5 mL/kg/min) with small MVV scores were unable to meet the ventilatory requirements to do prolonged work with a respirator. If this ability is decreased even further while performing arm work, the present standards for selecting firefighters may have to be adjusted for both men and women.

Arm Peak VO_2

Arm Peak VO_2 was measured as the maximal oxygen consumption obtained during an incremental arm exercise test. This value was significantly reduced while wearing an

APR (-6.7% mL/kg/min; -8.3% L/min) for the M-F combined group. Maximum heart rates and minute ventilation for arm peak with and without the respirator were also significantly reduced for the M-F combined group (1.6%, 18.3%, see Table 5). Although there was a significant difference for the female group (-7.4% mL/kg/min and -11.0% L/min), the male group (6.3% and 6.7%) was not significantly different with and without the APR for the Arm Peak Test. This may be due to the greater arm strength for male subjects enabling them to maintain a similar VO_2 while wearing the respirator.

These results are consistent with other studies that evaluated the effects of respirator wear on work performance using legs only. Several studies (Craig et al., 1970; Raven et al., 1979; Mead, 1991; Townsend, 1991) found that the increased breathing resistance resulted in a decrease in VO_2 and $\dot{V}_E$ while wearing a respirator. The decrease in $\dot{V}_E$ has been associated with decreased time to exhaustion during an endurance test (Craig et al., 1970). This study found an 18.3%, 18.0% and a 15.74% decrease in minute ventilation for the M-F combined, male and female group respectively with the respirator. Townsend (1991) saw a 17.8% decrease in $\dot{V}_E$ with the APR in a study that involved 15 female subjects.

Further examination of the data showed that the mean peak VO_2 of the arms without the APR for the M-F combined group was 71% (mL/kg/min) and 72% (L/min) of the mean VO_{2max} of the legs without the APR. In addition, the arm peak with the APR was 67% (mL/kg/min) and 66% (L/min) of the legs without the APR (See Table 13). Franklin et al. (1983) found arm VO_2 to be 80% (L/min) of that for leg work VO_2 when both arm and leg work were performed on the cycle ergometer. The lower percent values between arms and legs seen in this study may be due to the comparison between a seated arm cranking versus an upright treadmill test. Other studies found VO_{2max} during arm exercise to be between 70% to 80% of max VO_2 during leg exercise (Toner et al., 1983; Vohac et al., 1975). Maximum values for HR, VT, blood lactate, and pulmonary ventilation are also lower with arm exercise (see Table 13). Therefore, this study is consistent with the findings of similar studies. The lower percentage of arm max is generally attributed to the relatively small muscle mass of the upper body used in arm ergometry, less mechanical efficiency with the arms, and an increase in lactate production at a given power output (Casaburi et al., 1992).

TABLE 13: ARM PEAK AS PERCENT OF TREADMILL TEST

VARIABLE	M-F W/O	COMB W	M W/O	M W	F W/O	F W
VO_2 (mL/kg/min)	71%	67%	74%	69%	68%	63%
VO_2 (L/min)	72%	66%	73%	66%	69%	62%
VT (mL/kg/min)	43%	45%	48%	49%	39%	41%
LA (mM/L)	92%	91%	92%	94%	90%	91%
HR (b/min)	96%	94%	95%	95%	96%	94%

W = with APR; W/O = without APR

Predicting Performance While Wearing an APR

The second purpose of this study was to predict sustained arm performance while wearing a respirator. Variables that had a significant Pearson r value were used in a step-wise multiple regression procedure to eliminate redundant tests and to identify those tests that best predict sustained arm performance with the APR. Significant values are presented in Table 11, and the step-wise regression scores are indicated in Table 12.

Several pulmonary function measures have been shown to be predictive of performance while wearing a respirator; these include, $MVV_{.25}$, PEF, and $FEV_{1.0}$ (Townsend, 1991; Wilson & Raven, 1989). Although this study also found significant correlations between these values, $FEV_{1.0}$ was found to be the most predictive of the pulmonary function measures for sustained arm performance while wearing the APR (r = .730; r^2 = .532). Since $FEV_{1.0}$ is reduced by an increase in airway resistance during forced expiration (West, 1987), $FEV_{1.0}$ may best reflect changes associated with air flow resistance due to respirator use. Although, for practical purposes, the MVV still may be the best test for predicting performance while using a respirator. Freedman (1970) determined that 50% of the MVV can be maintained for long periods of time. Since ventilatory requirements for a given task are known (approximately 40-50 L/min for wildland firefighting at a VO_2 of 22-25 ml/kg/min) the ventilatory reserves necessary for the job can be determined by calculating 50% of the MVV and adding 20-30 L/min for ventilatory drift that may occur with prolonged work (Tenney and Reese, 1968). MVV is correlated to $FEV_{1.0}$ and to body size (Freedman, 1970) and is dependent on vital capacity. Any increase in resistance will decrease ventilatory capacity. Therefore, the MVV provides a test that is simple to administer and is relatively inexpensive. It also takes into account the lung and chest wall mechanics as well as the respiratory muscle fatigue associated with sustained submaximal arm exercise and respirator resistance (Raven et al., 1979).

This study also focused on the ability of muscular fitness tests and the field performance measures such as the Pack Test to predict performance with the APR. The best predictors among the muscular fitness tests were the bench press and the arm curl ($\underline{R}$ = 0.694; $\underline{R}^2$ = 0.482). The bench press and arm curl measure the strength of the major muscles of the chest and arms. Therefore, muscular fitness of the chest and arms is related to the ability to perform while wearing an APR. This relationship, also exists for the tasks associated with wildland firefighting such as handline construction with shovels and Pulaskis (Sharkey et al., 1980).

The field test alone had a predictive value of $\underline{r}$ = -0.708 ($\underline{r}^2$ = 0.501) for arm endurance with the APR. When a step-wise regression was run for all the significant variables, the field test and leg max (L/min) proved to be the strongest predictors of arm performance with an APR ($\underline{R}$ = 0.864; $\underline{R}^2$ = 0.747). The field test significantly correlated with the step test ($\underline{r}$ = -0.455) and the leg max test ($\underline{r}$ = -0.576 L/min and -0.579 mL/kg-min^1) in this study. Therefore, the field test, as a predictor of arm endurance while using an APR, may be worth consideration in a search for a job-related test for the demands of wildland firefighting.

Chapter Six

SUMMARY AND CONCLUSION

The focus of this study was to determine the effects of wearing an APR on sustained work performance for upper body exercise. Nine male and nine female volunteers between the ages of 20 and 36 underwent a battery of tests that included: two 30-minute arm ergometry tests (one with and one without the APR), two peak VO_2 arm tests (one with and one without the APR), pulmonary function tests, muscular fitness tests, a maximum graded exercise test, and a field (pack) test.

The results of this study showed that the respirator significantly reduced arm peak VO_2 (6.7% mL/kg/min; 8.3% L/min), V_E (18.3%), and HR (1.6%) for the M-F combined group. Although there was a 5.5% or 2.15 watt reduction in sustained arm work, the difference was not statistically significant.

Another objective of the study was to attempt to predict arm endurance (30-minute arm ergometry test) while wearing an APR. There were several tests that correlated ($p<.01$) with arm endurance while wearing the respirator, but a multiple regression analysis determined the field test and leg max (L/min) to be the strongest predictors (R = 0.864 and R^2 = 0.747). The field test and the $FEV_{1.0}$ were also highly predictive (R = 0.832; R^2 = 0.692).

Recommendations for Further Research

1. In order to determine minute by minute information on VO_2 V_E, and breath frequency associated with prolonged arm exercise and respirator use, a study using gas analysis during an endurance test with and without the APR for a longer period, or to exhaustion, could be utilized. This would allow a comparison of how entrainment, V_E and VO_2 was affected over a long period of time with the respirator.
2. Since the field test was a good predictor of arm work with the respirator, a comparisons of this test with specific firefighting tasks and an evaluation of this test as a candidate for screening wildland firefighters may be beneficial.

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Informed Consent Form

APPENDIX A

This study will investigate the use of field, fitness, and pulmonary function tests to predict a wild land firefighters ability to wear an air purifying respirator (APR) during prolonged work with the arms. The results of this research will provide important information about the effects of wearing an APR, as well as determining an objective measure of a person's ability to wear an APR while working.

Participation in this research will include a maximal oxygen consumption test (10-15 minutes long) on the treadmill, a maximal upper body exercise test, 2 prolonged arm endurance tests, one with the APR and one without (each lasting 20-30 minutes), a battery of muscular fitness tests (pushups, situps etc.), pulmonary function testing, a bench stepping test (5 minutes long), and a field test consisting of a 3 mile hike while wearing the APR and a 45 lb. pack (30-60 minutes long). These tests will be divided into 6 separate days over the course of 5-6 weeks. After completion of each of the aerobic tests a blood sample will be taken by the finger stick method. Less than 1cc of blood will be taken and this blood will be analyzed for lactate.

There is a possibility that certain abnormal responses could occur during the tests. These include fainting, irregular heart beat, and breathlessness. A preliminary screening form will be required prior to testing, and subjects will be observed during the test to minimize the danger of abnormal responses. From these tests you will gain an assessment of your strength and fitness and knowledge of your pulmonary function.

Individuals trained in exercise physiology, CPR, and first aid will conduct the tests. If you experience any discomfort (such as leg cramps, dizziness, or severe fatigue) at any time you may stop the test. Any further questions may be addressed to Tara Townsend (542-0712) or Theresa Green (721-0815).

"In the event physical injury results from biomechanical or behavioral research the human subject should individually seek appropriate medical treatment and shall be entitled to reimbursement or compensation consistent with the self insurance program for Comprehensive Administration under the authority of MCAA Title 2, Chapter 9 or by satisfaction of the claim or judgement by a means provided by MCA, Section 2-9-315. In the event of a claim for such physical injury, further information may be obtained from the University Legal Counsel."

I have read the above statements, and thoroughly know, understand and appreciate the risks involved. I authorize Brian Sharkey, Tara Townsend, Theresa Green, and such assistants they may designate, to administer and conduct the test as safely as possible and with a minimum amount of discomfort.

Signature of participant____Date_____

Investigator____Date_____

APPENDIX B

Before volunteering to be a subject in this study, please answer the following questions:

Yes	No	
☐	☐	Have you ever been diagnosed with any disorders of the heart?
☐	☐	Have you ever fainted or had feelings of dizziness?
☐	☐	Do you have high blood pressure?
☐	☐	Do you have any bone, joint, muscle, or tendon problems which might be made worse by exercise?
☐	☐	Does your family have a history of cardiovascular disease?
☐	☐	Do you have asthma or exercise induced asthma?
☐	☐	Do you have any restrictive or obstructive lung problems?

Sitting Blood Pressure______________

Sitting Pulse______________________

If you have answered no to all of these questions and have pulse and blood pressure readings within the normal range, you have reasonable assurance of suitability for this study.

APPENDIX C

PERCEIVED EXERTION SCALE (RPE)

0	NOTHING AT ALL
0.5	VERY, VERY WEAK
1	VERY WEAK
2	WEAK
3	MODERATE
4	SOMEWHAT STRONG
5	STRONG
6	
7	VERY STRONG
8	
9	
10	VERY, VERY STRONG
*	MAXIMAL

Borg (1982)

APPENDIX D

CHARACTERISTICS OF SUBJECTS (n = 18)

	AGE (YRS)	WEIGHT(LBS)	HEIGHT (IN)	GENDER	LA A.ENDW/O (Mm/L)	LA A.ENDW/	LA LEG MAX	LA A PK W/
Type:	Real	Real	Real	Category	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Nominal	Continuous	Continuous	Continuous	Continuous
Format:	Free Format...	Free Format...	Free Format...	•	Free Format Fixed	Free Format...	Free Format...	Free Format...
Dec. Places:	3	3	3	•	3	3	3	3
Mean:	24.944	157.778	67.333	•	3.221	3.214	9.450	8.608
Std. Deviation:	4.595	36.610	3.742	•	1.118	1.770	3.183	1.960
Std. Error:	1.083	8.629	.882	•	.263	.417	.750	.462
Variance:	21.114	1340.301	14.000	•	1.249	3.134	10.133	3.840
Coeff. of Variation:	.184	.232	.056	•	.347	.551	.337	.228
Minimum:	20.000	117.000	63.000	M	1.650	1.000	2.550	5.700
Maximum:	36.000	265.000	76.000	F	6.000	8.400	15.900	12.600
Range:	16.000	148.000	13.000	1.000	4.350	7.400	13.350	6.900
Count:	18	18	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0	0	0
Sum:	449.000	2840.000	1212.000	•	57.971	57.850	170.100	154.950
Sum of Squares:	11559.000	470874.000	81846.000	•	207.932	239.207	1779.705	1399.138

	AGE (YRS)	WEIGHT(LBS)	HEIGHT (IN)	GENDER	LA A.ENDW/O (Mm/L)	LA A.ENDW/	LA LEG MAX	LA A PK W/
1	36.000	122.000	64.000	F	3.200	3.000	6.900	6.300
2	23.000	123.000	63.000	F	3.221	4.200	10.350	8.950
3	23.000	140.000	65.000	F	2.700	2.700	10.050	7.500
4	21.000	128.000	64.000	F	1.650	1.000	5.550	9.000
5	27.000	117.000	63.000	F	1.650	1.800	8.250	7.500
6	23.000	155.000	67.000	F	1.800	1.950	10.050	7.200
7	22.000	138.000	65.000	F	3.300	2.400	10.050	5.700
8	27.000	131.000	64.000	F	3.000	2.100	8.400	6.450
9	28.000	128.000	66.000	F	3.600	2.400	2.550	6.300
10	21.000	175.000	66.000	M	3.600	3.300	15.900	11.250
11	24.000	165.000	72.000	M	3.750	2.850	7.500	9.600
12	25.000	168.000	72.000	M	3.600	2.400	10.050	8.400
13	36.000	175.000	68.000	M	6.000	5.400	10.800	12.600
14	21.000	195.000	70.000	M	2.600	5.850	9.750	10.100
15	25.000	155.000	66.000	M	4.700	8.400	9.450	10.200
16	20.000	265.000	76.000	M	3.000	2.700	6.900	7.200
17	24.000	200.000	72.000	M	4.500	3.300	12.000	10.200
18	23.000	160.000	69.000	M	2.100	2.100	15.600	10.500

APPENDIX D CONTINUED

	LA A PK W/O	LA STEP TST	LA FIELD TEST	STEP TEST (MI/KG/ MIN)	LEG MAX (ML/KG/MIN)	LEG MAX (L/...	A PK W/O (ml/kg/min)
Type:	Real	Real	Real	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Format:	Free Format...	Free Format...	Free Format...	Free Format Fixed	Free Format Fixed	Free Format...	Free Format Fixed
Dec. Places:	3	3	3	3	3	3	3
Mean:	8.774	2.447	2.919	45.833	46.356	3.330	33.056
Std. Deviation:	2.057	1.264	1.746	6.784	7.390	.920	7.358
Std. Error:	.485	.298	.412	1.599	1.742	.217	1.734
Variance:	4.230	1.598	3.049	46.029	54.611	.846	54.133
Coeff. of Variation:	.234	.517	.598	.148	.159	.276	.223
Minimum:	6.300	.700	.900	35.000	32.900	2.050	23.500
Maximum:	12.450	4.950	7.350	58.000	57.900	4.780	52.000
Range:	6.150	4.250	6.450	23.000	25.000	2.730	28.500
Count:	18	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0	0
Sum:	157.924	44.050	52.550	825.000	834.400	59.940	595.000
Sum of Squares:	1457.461	134.973	205.247	38595.000	39607.460	213.980	20586.320

	LA A PK W/O	LA STEP TST	LA FIELD TEST	STEP TEST (MI/KG/ MIN)	LEG MAX (ML/KG/MIN)	LEG MAX (L/...	A PK W/O (ml/kg/min)
1	6.750	1.050	2.400	48.000	45.400	2.590	36.200
2	7.500	4.200	3.600	35.000	41.400	2.360	24.200
3	7.200	2.550	1.500	39.000	32.900	2.100	29.100
4	6.600	.700	1.800	42.000	50.400	2.880	32.900
5	8.800	2.700	.900	49.000	38.700	2.050	23.500
6	6.300	.900	1.500	51.000	51.500	3.600	38.200
7	8.700	2.100	1.800	40.000	45.600	2.780	29.200
8	7.500	1.050	4.800	47.000	42.400	2.500	26.600
9	6.750	1.050	3.300	50.000	41.900	2.410	26.600
10	10.650	3.000	1.800	40.000	56.700	4.400	38.900
11	12.400	1.950	4.950	41.000	54.700	4.090	36.200
12	8.774	3.000	3.450	58.000	57.900	4.400	52.000
13	12.450	2.400	7.350	58.000	56.100	4.480	33.500
14	7.200	2.250	1.200	46.000	41.900	3.810	24.400
15	9.150	4.950	5.400	42.000	40.000	2.800	44.100
16	8.400	4.350	2.300	41.000	39.400	4.780	32.800
17	10.950	3.750	1.500	42.000	43.300	3.810	33.500
18	11.850	2.100	3.000	56.000	54.200	4.100	33.100

APPENDIX D CONTINUED

	A PK W (ml/kg/min)	A Pk W/O (L/m)	A Pk W (L/m)	A Pk MAX VE W/O (L/m)	A Pk MAX VE W (L/m)	A PK MAX HR W/O
Type:	Real	Real	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Format:	Free Format Fixed	Free Format Fi...	Free Format...	Free Format Fixed	Free Format Fixed	Free Format Fixed
Dec. Places:	3	3	3	3	3	3
Mean:	30.817	2.388	2.233	107.640	87.917	179.000
Std. Deviation:	6.637	.798	.779	31.887	23.468	10.884
Std. Error:	1.564	.188	.184	7.516	5.531	2.565
Variance:	44.054	.637	.607	1016.764	550.732	118.471
Coeff. of Variation:	.215	.334	.349	.296	.267	.061
Minimum:	19.200	1.200	1.020	58.400	45.200	157.000
Maximum:	44.300	3.950	4.010	182.500	133.600	194.000
Range:	25.100	2.750	2.990	124.100	88.400	37.000
Count:	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0
Sum:	554.700	42.990	40.190	1937.516	1582.500	3222.000
Sum of Squares:	17842.930	113.499	100.051	225838.774	148490.565	578752.000

	A PK W (ml/kg/min)	A Pk W/O (L/m)	A Pk W (L/m)	A Pk MAX VE W/O (L/m)	A Pk MAX VE W (L/m)	A PK MAX HR W/O
1	37.500	2.000	2.100	86.300	70.700	163.000
2	22.800	1.350	1.300	87.100	74.910	193.000
3	28.100	1.850	1.800	82.400	70.800	190.000
4	34.800	2.000	2.000	70.100	78.100	194.000
5	19.200	1.200	1.020	58.400	45.200	183.000
6	31.600	2.700	2.200	95.100	65.900	167.000
7	26.200	1.800	1.600	92.200	73.800	171.000
8	22.500	1.800	1.300	109.240	70.800	176.000
9	24.300	1.500	1.400	76.500	65.120	190.000
10	29.100	3.000	2.300	121.100	90.700	189.000
11	35.800	2.700	2.700	124.300	109.400	187.000
12	44.300	3.900	3.400	154.400	126.400	170.000
13	28.900	2.600	2.300	144.600	103.900	171.000
14	27.800	2.100	2.400	90.900	93.500	157.000
15	37.400	3.100	2.620	116.700	94.400	178.000
16	33.400	3.950	4.010	182.500	133.600	175.000
17	31.500	2.960	2.790	130.880	112.250	183.000
18	39.500	2.480	2.950	114.796	103.020	185.000

APPENDIX D CONTINUED

	A PK MX HR W	A END W (WATTS	A END W/O (WATTS)	FIELD TEST (SEC)	FIELD T. PULSE (b/m)	MVV (L/m)
Type:	Real	Real	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Format:	Free Format Fixed	Free Format Fl...	Free Format Fixed	Free Format Fixed	Free Format Fixed	Free Format...
Dec. Places:	3	3	3	3	3	3
Mean:	176.722	54.041	57.192	2547.833	147.389	156.667
Std. Deviation:	13.123	27.156	27.695	326.371	14.681	32.485
Std. Error:	3.093	6.401	6.528	76.926	3.460	7.657
Variance:	172.212	737.436	767.032	106518.147	215.546	1055.294
Coeff. of Variation:	.074	.503	.484	.128	.100	.207
Minimum:	149.000	9.000	7.500	2062.000	120.000	114.000
Maximum:	194.000	96.000	111.600	3109.000	180.000	220.000
Range:	45.000	87.000	104.100	1047.000	60.000	106.000
Count:	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0
Sum:	3181.000	972.740	1029.460	45861.000	2653.000	2820.000
Sum of Squares:	565081.000	65104.371	71916.649	118656993.000	394687.000	459740.000

	A PK MX HR W	A END W (WATTS	A END W/O (WATTS)	FIELD TEST (SEC)	FIELD T. PULSE (b/m)	MVV (L/m)
1	165.000	69.000	81.000	2183.000	138.000	131.000
2	194.000	30.000	26.980	2650.000	150.000	121.000
3	185.000	30.000	30.000	3006.000	180.000	116.000
4	191.000	22.800	31.860	2643.000	145.000	145.000
5	182.000	9.000	7.500	2966.000	140.000	139.000
6	149.000	81.000	69.240	2435.000	155.000	114.000
7	155.000	34.500	45.000	2940.000	120.000	124.000
8	172.000	28.980	35.800	2292.000	160.000	163.000
9	192.000	22.500	30.000	3109.000	132.000	126.000
10	184.000	47.880	52.500	2705.000	150.000	170.000
11	186.000	76.460	70.460	2158.000	170.000	158.000
12	169.000	90.060	97.500	2062.000	140.000	194.000
13	177.000	85.500	87.000	2158.000	163.000	173.000
14	164.000	79.800	77.940	2510.000	140.000	180.000
15	178.000	51.300	51.000	2540.000	130.000	149.000
16	165.000	96.000	111.600	2370.000	150.000	220.000
17	188.000	66.480	66.000	2820.000	150.000	192.000
18	185.000	51.480	58.080	2314.000	140.000	205.000

APPENDIX D CONTINUED

	PIF (L/s)	FEF 25-75 (L/s)	PEF (L/s)	FEV 1.0 (L)	FVC (L)	leg p. (1RM)	bench p. (1RM)	arm curl (1RM)
Type:	Real	Real	Real	Real	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Format:	Free Format...	Free Format ...	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...	Free Format...
Dec. Places:	3	3	3	3	3	3	3	3
Mean:	6.654	4.603	9.279	3.953	4.564	398.889	118.333	70.556
Std. Deviation:	1.740	1.511	2.626	.877	1.090	104.608	47.589	31.007
Std. Error:	.410	.356	.619	.207	.257	24.656	11.217	7.308
Variance:	3.027	2.282	6.896	.769	1.189	10942.810	2264.706	961.438
Coeff. of Variation:	.261	.328	.283	.222	.239	.262	.402	.439
Minimum:	3.970	2.900	5.920	2.860	2.900	220.000	65.000	35.000
Maximum:	10.010	8.430	16.130	5.750	6.430	570.000	210.000	135.000
Range:	6.040	5.530	10.210	2.890	3.530	350.000	145.000	100.000
Count:	18	18	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0	0	0
Sum:	119.770	82.860	167.020	71.150	82.150	7180.000	2130.000	1270.000
Sum of Squares:	848.399	420.220	1666.995	294.310	395.139	3050050.000	290550.000	105950.000

	PIF (L/s)	FEF 25-75 (L/s)	PEF (L/s)	FEV 1.0 (L)	FVC (L)	leg p. (1RM)	bench p. (1RM)	arm curl (1RM)
1	5.640	4.830	7.370	3.190	3.290	310.000	80.000	55.000
2	5.840	4.060	7.710	2.930	3.160	310.000	70.000	35.000
3	6.510	4.530	6.810	2.860	2.900	245.000	65.000	40.000
4	3.970	3.970	5.920	3.290	3.730	320.000	75.000	50.000
5	4.760	3.990	6.930	2.930	3.270	300.000	80.000	50.000
6	5.230	2.900	10.500	3.660	4.870	395.000	130.000	60.000
7	5.530	3.810	6.670	3.690	4.490	325.000	80.000	40.000
8	8.970	4.960	10.400	3.670	3.670	395.000	75.000	45.000
9	5.400	3.160	6.960	2.930	3.470	220.000	65.000	35.000
10	6.650	3.510	10.160	4.210	5.410	520.000	195.000	100.000
11	6.040	3.050	10.400	3.830	5.120	465.000	150.000	100.000
12	7.480	4.680	11.100	4.270	4.960	485.000	155.000	100.000
13	8.060	8.190	11.440	5.400	5.400	485.000	135.000	60.000
14	9.790	4.120	7.620	4.840	6.430	370.000	110.000	65.000
15	5.800	5.260	16.130	4.730	5.570	435.000	125.000	80.000
16	10.010	8.430	12.750	5.750	6.070	570.000	210.000	135.000
17	8.380	4.470	9.930	4.390	5.100	535.000	185.000	110.000
18	5.710	4.940	8.220	4.580	5.240	495.000	145.000	110.000

APPENDIX D CONTINUED

	situps (1min)	pullups (max #)	pushup (1min)	VT TM VO2 (ML/KG/MIN)	VT TM VE (L/m)	VT APK W VO2 (ML/KG/MIN)
Type:	Real	Real	Real	Real	Real	Real
Source:	User Entered	User Entered	User Entered	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous	Continuous	Continuous	Continuous
Format:	Free Format...	Free Format...	Free Form...	Free Format Fixed	Free Format Fixed	Free Format Fixed
Dec. Places:	3	3	3	3	3	3
Mean:	41.111	7.252	36.689	36.378	76.441	16.222
Std. Deviation:	9.970	6.075	18.237	7.987	24.209	4.093
Std. Error:	2.350	1.432	4.298	1.882	5.706	.965
Variance:	99.399	36.910	332.575	63.784	586.073	16.755
Coeff. of Variation:	.243	.838	.494	.220	.317	.252
Minimum:	23.000	.786	6.000	24.000	45.270	8.600
Maximum:	62.000	22.000	76.000	53.400	121.220	24.800
Range:	39.000	21.214	70.000	29.400	75.950	16.200
Count:	18	18	18	18	18	18
Missing Cells:	0	0	0	0	0	0
Sum:	740.000	130.539	664.000	654.800	1375.940	292.000
Sum of Squares:	32112.000	1574.155	30148.000	24904.500	115141.624	5021.720

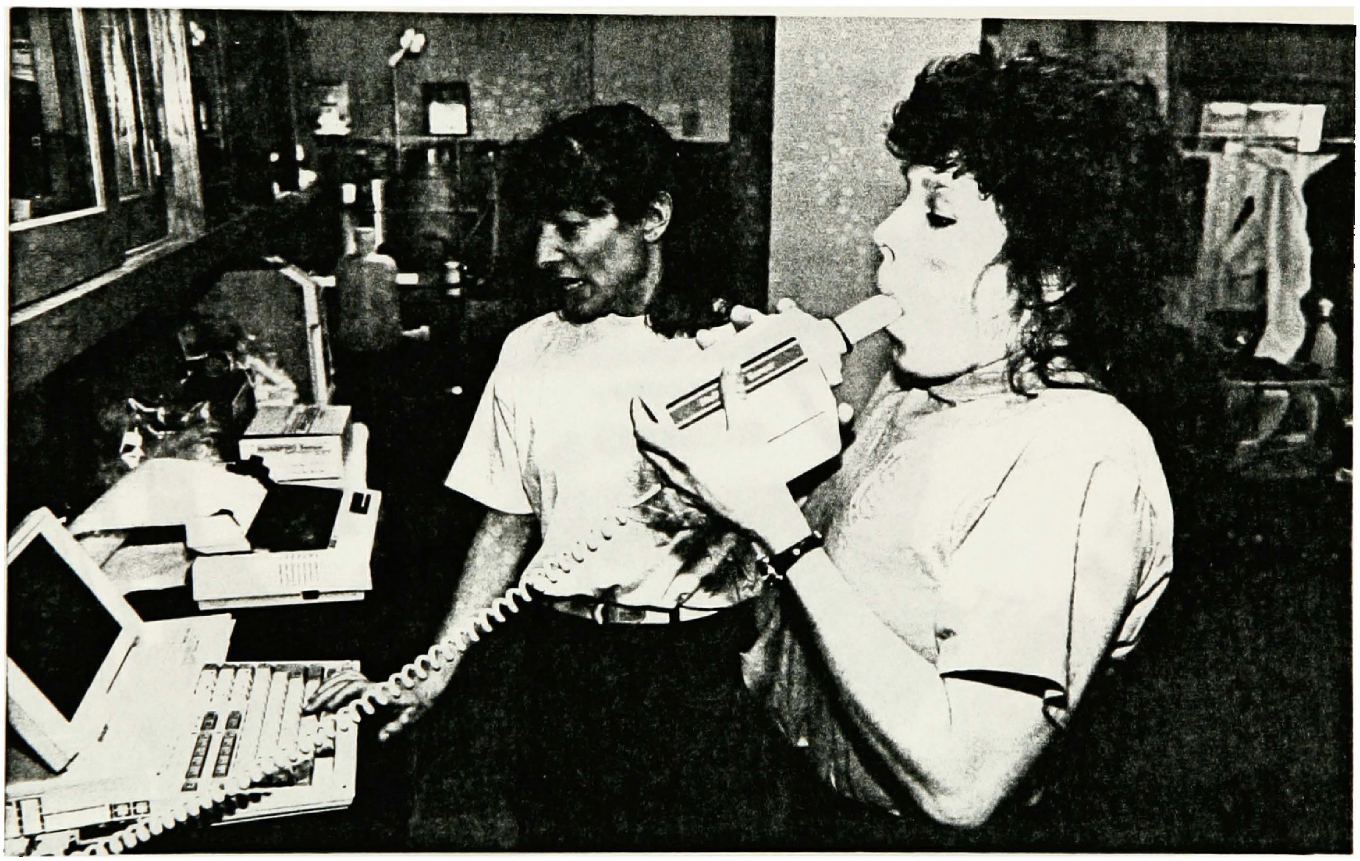
	situps (1min)	pullups (max #)	pushup (1min)	VT TM VO2 (ML/KG/MIN)	VT TM VE (L/m)	VT APK W VO2 (ML/KG/MIN)
1	47.000	8.000	50.000	39.200	75.870	15.900
2	36.000	.894	17.000	33.800	67.100	15.700
3	33.000	.786	12.000	41.900	63.610	10.600
4	36.000	3.000	35.000	24.200	45.270	14.300
5	50.000	9.000	40.000	28.800	45.740	13.700
6	41.000	6.000	51.000	36.500	58.890	22.200
7	50.000	1.000	16.000	42.300	98.500	8.600
8	32.000	2.000	34.000	32.000	63.860	14.400
9	27.000	.859	6.000	35.800	63.860	14.200
10	48.000	11.000	76.000	49.200	101.380	11.800
11	35.000	9.000	50.000	26.900	46.350	16.700
12	44.000	14.000	42.000	53.400	121.220	24.800
13	53.000	16.000	34.000	43.800	113.150	15.700
14	33.000	1.000	17.000	32.700	82.430	20.400
15	23.000	9.000	30.000	34.800	76.690	18.500
16	44.000	6.000	46.000	35.900	114.470	16.400
17	46.000	11.000	52.000	24.000	58.630	21.200
18	62.000	22.000	56.000	39.600	78.920	16.900

APPENDIX D CONTINUED

	VT APK W/O VO2 (ML/KG/MIN)	VT APK W VE (L/MIN)	VT APK W/O VE (L/MIN)
Type:	Real	Real	Real
Source:	User Entered	User Entered	User Entered
Class:	Continuous	Continuous	Continuous
Format:	Free Format Fixed	Free Format Fixed	Free Format Fixed
Dec. Places:	3	3	3
Mean:	15.572	37.426	38.410
Std. Deviation:	3.477	13.612	11.214
Std. Error:	.820	3.208	2.643
Variance:	12.092	185.290	125.753
Coeff. of Variation:	.223	.364	.292
Minimum:	10.200	18.800	19.900
Maximum:	21.500	65.200	56.500
Range:	11.300	46.400	36.600
Count:	18	18	18
Missing Cells:	0	0	0
Sum:	280.300	673.670	691.380
Sum of Squares:	4570.450	28362.772	28693.700

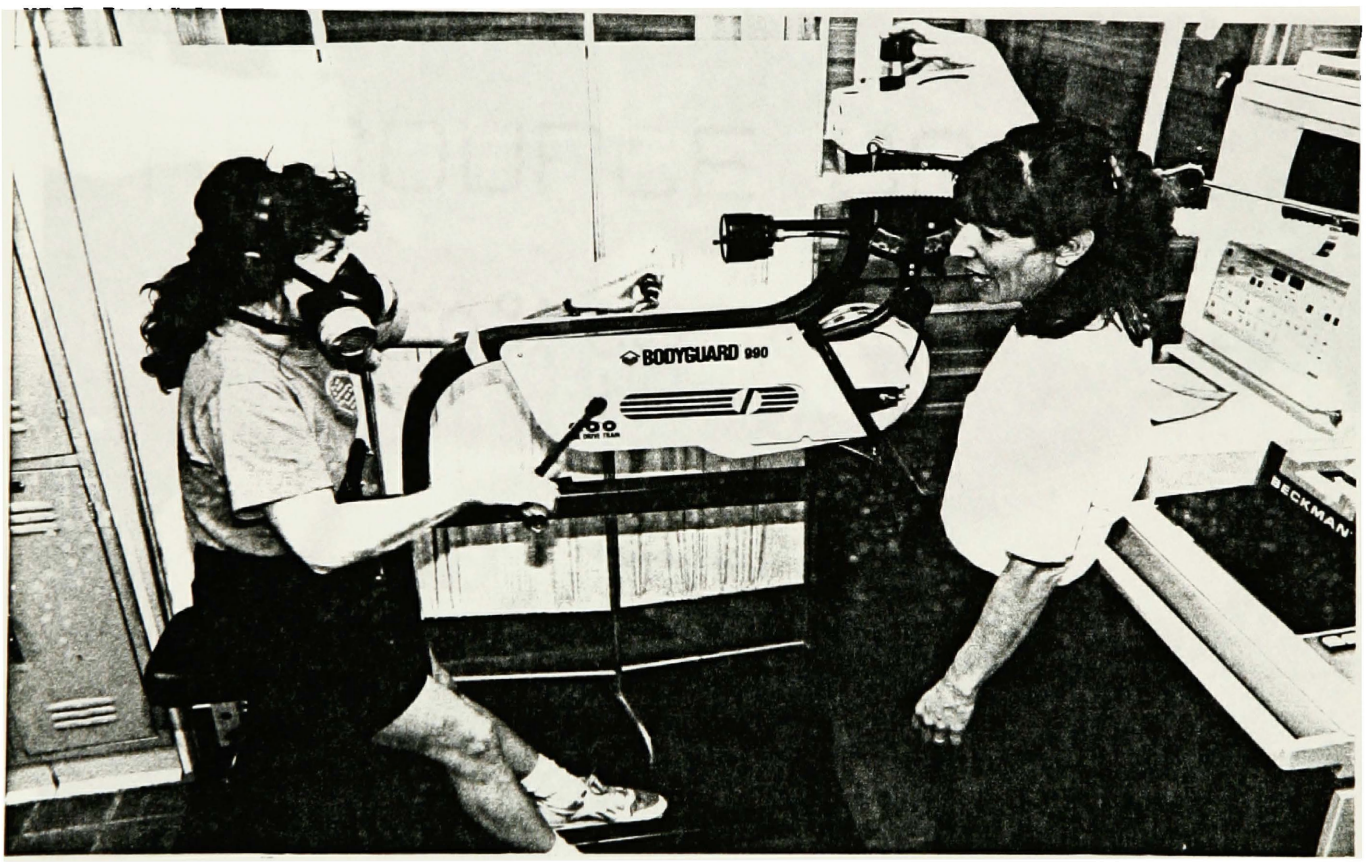
	VT APK W/O VO2 (ML/KG/MIN)	VT APK W VE (L/MIN)	VT APK W/O VE (L/MIN)
1	16.800	25.400	30.500
2	11.000	43.500	27.900
3	10.200	22.400	24.700
4	12.600	22.600	19.900
5	12.900	27.500	27.800
6	19.300	47.600	42.900
7	12.400	18.800	39.200
8	13.700	36.300	38.800
9	13.400	27.400	23.500
10	18.100	31.200	38.800
11	19.900	35.000	43.100
12	19.900	52.900	38.200
13	15.800	35.900	54.800
14	11.300	65.200	52.900
15	17.400	34.700	33.700
16	16.300	52.960	56.500
17	17.800	60.870	49.200
18	21.500	33.440	48.980

APPENDIX E



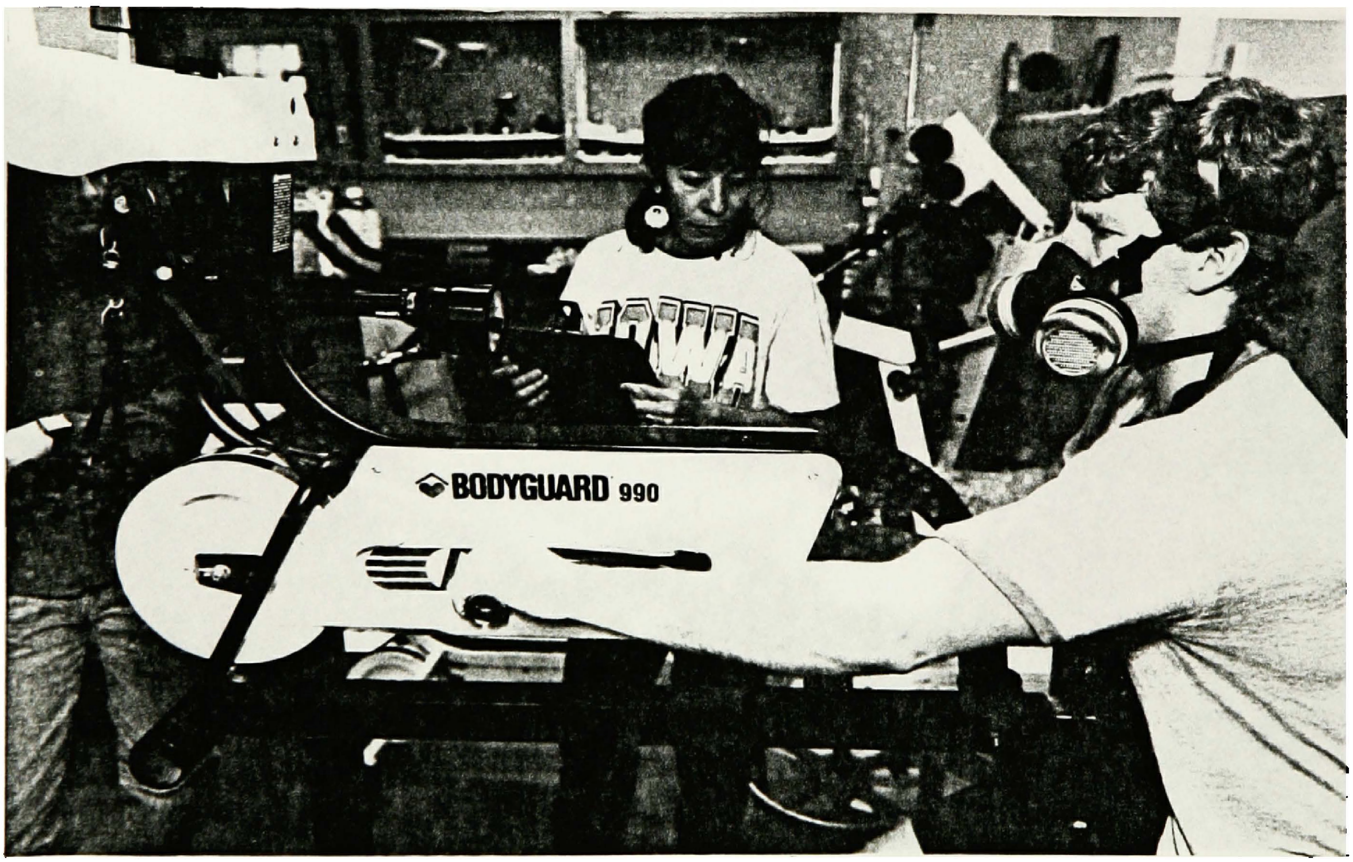
E: PULMONARY FUNCTION TESTING

APPENDIX F



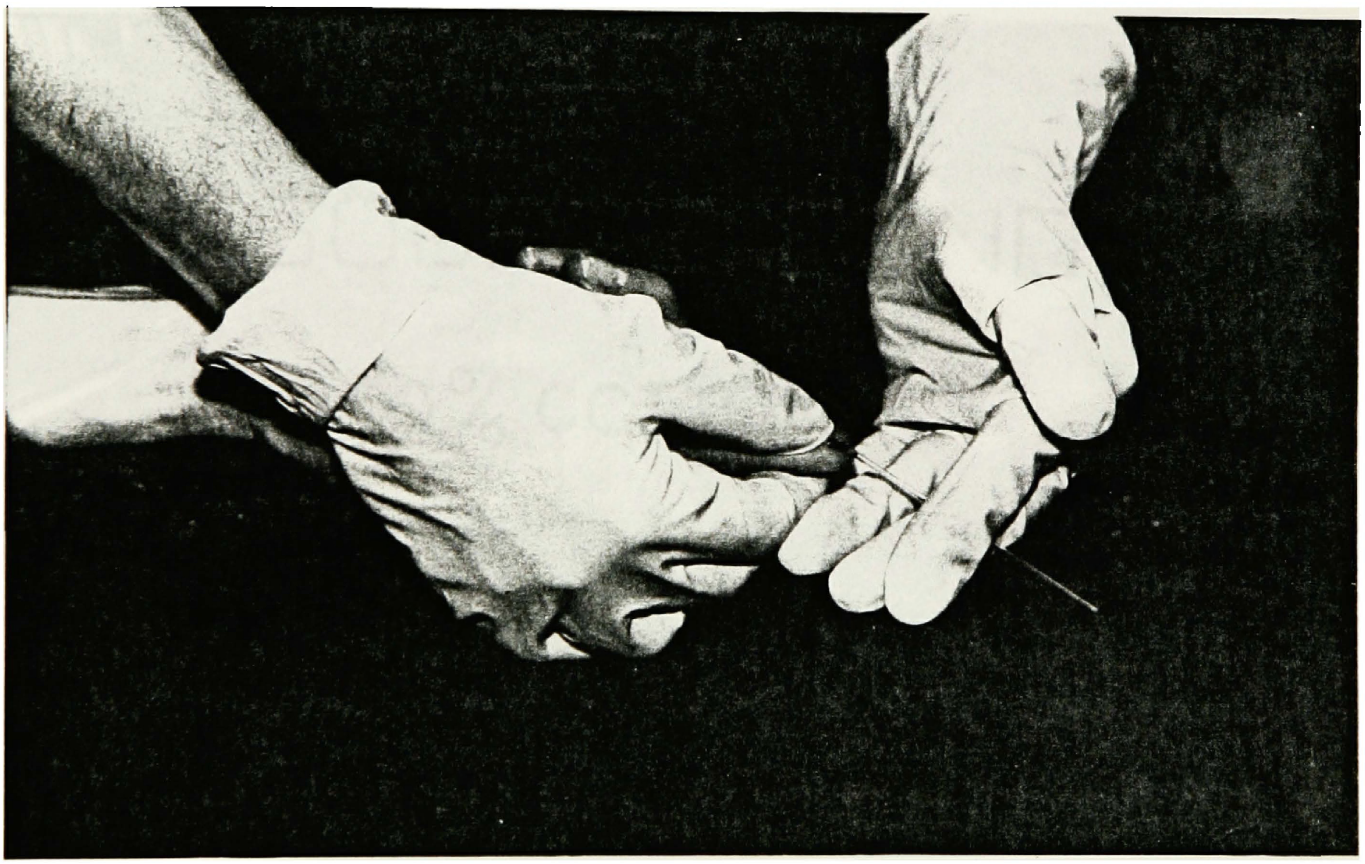
F: ARM PEAK VO_2 TEST WITH RESPIRATOR

APPENDIX G



G: 30-MINUTE ARM ERGOMETRY TEST WITH RESPIRATOR

APPENDIX H



H: FINGER STICK AND BLOOD DRAW FOR LACTATE ANALYSIS

APPENDIX I

I: PIPETTING BLOOD INTO CENTRIFUGE TUBE FOR LACTATE ANALYSIS

APPENDIX J

J: POSITIONING CENTRIFUGE TUBE FOR YSI 2300
LACTATE ANALYZER.