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The effect of respirator wear on work capacity and pulmonary function in female subjects

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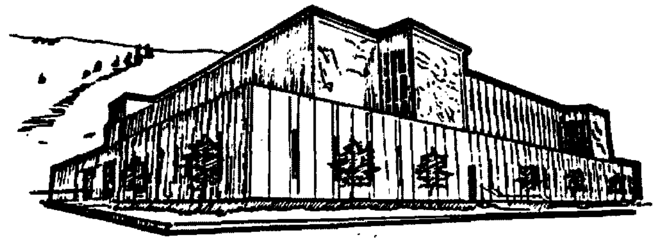

The Effect of Respirator Wear on Work Capacity and

Pulmonary Function in Female Subjects

By

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ABSTRACT

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The Effect of Respirator Wear on Pulmonary Function and Work Capacity in Female Subjects (54 pgs.)

Director: Dr. Brian J. Sharkey

The purpose of this study was to examine the effect of air purifying respirators on the work capacity of female subjects. The other objective of this research was to investigate FEV1.0, FEF, FEV1.0/FVC, PEF and MVV.25 as candidates for a screening method for the determination of a workers ability to tolerate respirator wear.

Fifteen female subjects performed a battery of pulmonary function tests. The MVV.25 was measured both with and without the respirator. Subjects performed two maximal treadmill tests at a speed of 4 or 3.5mph with grade increases of 2.5% every 1-2 minutes. One treadmill test was performed while wearing the respirator, and the results compared to another maximal treadmill test without the respirator.

The results of this study showed that the respirator significantly ($p<0.05$) decreased; the VO2max (12.6%); MVV.25 (25.2%); VEmax (17.8%); and the ventilatory threshold (10.7%). The respirator was also found to significantly decrease both the ventilation and VO2 at submaximal workloads (8.2% and 7.6% respectively). The respirator also caused an increase in subjects' perception of breathlessness. Claustrophobia forced one subject to end the respirator trial prematurely.

Multiple linear regression analysis showed that the MVV.25 with the respirator, along with height and weight could predict a subjects VO2max while wearing the respirator (R=.7556;R-squared=.5710).

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Chapter One

THE PROBLEM

Introduction

Each summer thousands of forest firefighters are exposed to the hazards of smoke. In the past firefighters have only used a wet handkerchief to combat the problems of exposure to smoke. During the Yellowstone Park fires of 1988, 12,000 respiratory problems were reported by firefighters (Missoula Technology and Development Center, 1990).

Recently, there have been a variety of studies on the effects of smoke exposure. Some of the effects of exposure to smoke include a significant decrease in forced expiratory volume in 1 second (FEV1.0) and a decrease in forced expiratory flow (FEF) (Sherman et al., 1989; Large et al., 1990; Rothman et al., 1990; Harrison et al., 1990; Sparrow et al., 1982; Sheppard et al., 1986). The earliest abnormal response to smoke may be changes in airway responsiveness (Sherman et al., 1989). Sherman and associates (1989) found a significant increase in airway responsiveness as measured by methacholine as long as 24 hours after exposure to smoke. Harrison and coinvestigators (1990) studied 63 hotshot crew members and found that airway reactivity increased significantly. These authors observed the hotshot crew members for an entire fire season and also noted an increase in respiratory and related symptoms. Crew members exhibited an increase in nose and eye irritation, cough, sore throat, and chest tightness. Some studies have also noted an increase in eye and respiratory symptoms after the fire season (Rothman et al., 1990).

Sensory irritants in wood smoke, like acrolein, have been associated with lung tissue damage and respiratory complications in rats (Packham et al., 1978). An increase in airway resistance has been postulated to be a risk factor for subsequent development of chronic obstructive pulmonary disease (Orie et al., 1961).

Sparrow and associates (1982) found that structural firefighters had a greater loss in pulmonary function (forced vital capacity and FEV1) than nonfirefighters. These effects were substantiated in 1986 (Sheppard et al.). These authors showed that routine firefighting causes a high frequency of acute decrements in lung function, decrements which can last as long as 18 hours. In a study of spontaneous inhalation of douglas fir smoke in goats, evidence of airway edema and retained secretions, suggested that inhalation injury causes increased endothelial permeability (Sharar et al., 1988). Smoke contaminants may also be cancer causing, as organic extracts of forest fire smoke particles have been found to be mutagenic (Viau et al., 1982).

Based on the research regarding the effects of smoke on pulmonary function, many researchers have advocated the use of respiration protective devices (Rothman et al., 1990; Sheppard et al., 1986). Air purifying respirators have been suggested to combat the problem of smoke exposure in wildland firefighters. The physiological consequences of wearing respirators have been considered in several studies (Raven, Dodson, Davis, 1979). The primary effects of wearing a respirator include: increase resistance to air flow, increase in respiratory dead space, additional heat stress, cardiovascular and metabolic adjustments, and psychological distress (Raven et al., 1979; Morgan 1983; Hodous 1986).

Investigations using air purifying respirators have shown that subjects have a decreased work capacity (De V Martin, 1972; Craig et al., 1970; Johnson and Berlin, 1974). Breathing against resistance during work contributes to the decrement in work capacity. This decrement is thought to occur due to respiratory fatigue, inadequate ventilation, CO2 rebreathing, or a shift to anaerobic pathways which causes an increase in the rate of accumulation of an oxygen debt (Raven et al., 1979). The increase in respiratory deadspace has been shown to increase alveolar CO2 tension and ventilation in dogs at rest (Barnett and Peters, 1960) and in humans at work (Jones et al. 1971).

It has been suggested that respirators are associated with an increase in cardiac output and stroke volume. This is due to the increase in thoracic activity used to overcome the added resistance to inspiration and expiration (Raven, 1979). These suggestions were based on a study using respirators during work, where minor changes in heart rate occurred along with a 24 percent increase in systolic blood pressure (Raven, 1979). Since significant thermal stress can occur with the use of the respirator and protective clothing, the combination can result in an increase in heart rate leading to cardiac stress (Hodous, 1986).

Although there is an Occupational Safety and Health Administration (OSHA) mandate requiring a medical evaluation for workers who will be required to wear respirators, there is little guidance to aid the clinician in the conduct of the evaluation. The need to develop an objective method to measure a workers ability to wear a respirator is an issue of medical, legal, and practical importance. A single pulmonary function test would be an ideal screening method. Since the primary effect of a respirator is an increase in inspiratory resistance, flow measurements would appear to be likely candidates for screening tests. Maximum voluntary ventilation in 15 seconds (MVV.25), forced vital capacity (FVC), FEV1.0 and FEV1.0/FVC have all been suggested by for this purpose (Wilson and Raven, 1989).

Statement of the Problem

This study was designed to determine the effect of air purifying respirators on the work capacity of female subjects. Since the vast majority of available research has been on self contained breathing apparatus, and demand respirators, and has focused primarily on male subjects, this study attempted to characterize the effects of air purifying respirators on female subjects. Another objective of this study was to investigate FEV1.0, FEV1.0/FVC, FEF25-75%, PEF and MVV.25 as candidates for a simple, inexpensive screening method for the determination of a workers ability to tolerate respirator wear.

Delimitations

The delimitations of the study included the following:

1. The sample population was limited to 15 volunteer, healthy women between the ages of 18 and 40 years old.

2. There was no minimum fitness requirement to be suitable for the study.

Limitations

The limitations of the study included the following:

1. The level of motivation in the subjects was not controlled in this study.

2. There may have been a learning component between the two treadmill tests, which could have increased efficiency. This was neither controlled nor compensated for in the study.

3. The health, nutrition, amount of stress, sleeping habits, and outside activities of the subjects were not entirely controlled prior to subjects' testing sessions.

Hypotheses

Each hypothesis was tested at the 0.05 level of significance. The hypotheses were as follows:

1. The MVV.25 without the respirator will be greater than the MVV.25 with the respirator.

2. For a given workload, the level of oxygen consumption without the respirator will be greater than that with the respirator.

3. The MVV.25 will be the best predictor of a subjects ability to do work with a respirator.

Definition of Terms

Forced Vital Capacity (FVC): The forced vital capacity is the maximal forced expiration following a maximal inspiration.

The Forced Expiratory Volume in 1 Second (FEV1.0): The forced expiratory volume is the volume of air exhaled during the first second of the FVC.

Maximal Voluntary Ventilation (MVV): The maximal voluntary ventilation in 15 seconds measures the rate and volume that a subject can maximally move air in and out of the lungs.

Maximal Oxygen Consumption (VO2max): Maximal oxygen consumption represents an individuals 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 is expressed in milliters/kg/min.

Minute Ventilation (VE): This represents the volume of air which moves in and out of the lungs during one minute of incremental exercise. It is expressed in liters/min.

Dyspnea: Dyspnea refers to the feeling of having difficulty in breathing. It is characterized by labored breathing.

Ventilatory Threshold (VT): The point where ventilation (L/min) increases disproportionately with VO2 (L/min).

Peak Expired Flow (PEF): Refers to the maximum flow rate achieved during a forced expiration (usually FVC).

Forced Expiratory Flow 25-75 (FEF25-75): This is the flow rate in liters per minute of air during the middle 50% of the forced vital capacity.

Basic Assumption

The basic assumption of the study was that all subjects gave their maximum effort in both the treadmill trials and the battery of pulmonary function tests.

Significance of the Study

The information derived from this study should be of value to persons implementing fitness standards and respirator qualifications for present and future employees in a number of different occupations. This study also contributed to the field of research on respirators, work capacity, pulmonary function, and how these variables interact in women.

This study provided some information about the fitness qualifications that are required for persons who may have to do prolonged work with a respirator. Most importantly, this study investigated a number of pulmonary function tests (MVV.25, FVC, FEV1.0/FVC, PEF, FEF25-75) as possible candidates as screening tests for a workers' ability to wear a respirator.

Chapter Two

REVIEW OF LITERATURE

This chapter contains a review of literature relevant to the study. The review is subdivided into the following sections: (1) The Physiology of Respirator Wear, (2) Pulmonary Factors Which Limit Work Capacity, (3) Predictors of Work Performance While Wearing a Respirator.

The Physiology of Respirator Wear

Effect on Work Performance

Most respirators are designed for submaximal work tasks. Some jobs, though, such as wildland firefighting may require bouts of maximal work performance. Studies which have examined the effects of air purifying respirators on work performance have shown that these devices reduce both maximal work capacity and endurance (Van Huss et al., 1967; De V Martin et al., 1972; Craig et al., 1970; Johnson et al., 1974). The reduction of work capacity in these studies was 21-27%, compared to work performance without the mask. The resistance to air flow is the major mechanism whereby respirators reduce work capacity.

Effect of Resistance to Air Flow

The major factor in the use of respirators and their influence on work capacity is the resistance to breathing. This factor has been the primary focus of past investigations.

The increase in resistance to breathing caused by the respirator will contribute to a decrease in time to exhaustion (Craig et al., 1970). With clean, new cartridges in an air purifying respirator the airway resistances are equal to 1-6 cm H2O, while expiratory resistances are about 1.5 cm H2O per liter per second (Kraut, 1988). Physiologic airway resistance in a healthy individual is between 0.4 and 2.6 cm H2O.

Resistance to both inspiration and expiration provide the major mechanism whereby respirators affect work capacity. Increases in respiratory resistance will result in a decreased submaximal oxygen consumption, and minute ventilation (Raven et al., 1979). In conjunction with an increase in resistance, respirator wear will also increase dead space. The combined effects of these variables will result in increased tidal volume, decreased respiratory frequency, and smaller decreases in alveolar ventilation (Gee et al., 1968; Raven et al., 1977; Stemler et al., 1977; Hermansen et al., 1972). While wearing a respirator a workers ability to achieve a set alveolar ventilation level will be accomplished by an increase in the minute ventilation. The amount of work required to move air through the respirator will be increased. This will be accomplished by increasing inspiratory pressure via the respiratory muscles (diaphragm, external and internal intercostal, scalene, sternomastoid and abdominal wall muscles).

The inspiratory/expiratory time ratio is altered by the increase in resistance via an increase in inspiratory time (Harber et al., 1984). This can cause the worker to experience the sensation of breathlessness (Kraut, 1988). The increase in expiratory pressure also leads to a more negative intrathoracic pressure. This may result in an increase in venous return and thus enhance cardiac filling pressure (Kraut, 1988). These effects may be significant in workers with cardiovascular disease.

There is a positive relationship between respirator filter resistance and the degree of dyspnea subjects experience (Lerman et al., 1983). As resistance is increased, physiological parameters are changed and this is reflected by in a change in the subjects perception of breathing. Lerman et al., (1983) concluded that any change in filter resistance will affect a workers ability to sustain ventilation. Consequently, there will be tradeoffs in the field. The amount of protection (and thus the degree of resistance imposed by the respirator filter) the work requires must be balanced by the effect of increasing resistance on the ability to perform work.

Lastly, in a small percentage of the population who are at risk for spontaneous development of a pneumothorax, the changes in thoracic pressure caused by the wear of the respirator may enhance this risk (Hodous, 1986).

Effects on Cardiovascular Function

Since intrathoracic pressure is decreased during inspiration and results in an increase in cardiac pressure, it might be expected that there will be significant EKG changes.

While some researchers (Raven et al., 1977; Chatterjee, 1969) have not seen any significant changes in either heart rate or EKG patterns, other researchers (Spioch et al., 1962) have shown increases in heart rate. Heart rates while wearing a respirator have not been shown to increase significantly (Hodous et al., 1983; Hodous et al., 1986; Harber et al., 1982). By virtue of their size and weight SCBA will increase cardiac demand. Kraut (1988) argues that heart rate is increased when wearing a SCBA, and that this will increase the demand placed on the heart. He recommends that respirator wear be contraindicated in workers with even minor cardiac abnormalities. Additionally, the added weight of these types of respirators (up to 35 lbs.) will increase the amount of heat stress the worker experiences. Heat stress will further increase cardiac demands. Respirators of the air purifying type will also substantially increase cardiac demand due to the additional thermal stress which they impose. This area has not been well addressed in the literature.

Blood pressure was shown to increase in one study (Spioch, 1962). Subjects in this study completed the Harvard step test both with and without a respirator. These authors reported a 24% increase in recovery systolic blood pressure while wearing the respirator.

Thermoregulatory Concerns

Heat stress is a concern for many respirator work situations, such as firefighting. The respirator itself will impose a heat stress as will the protective clothing that firefighters are required to wear.

When inspired air temperature is greater than body temperature, heat loss by the lungs will not occur and body temperature will increase (Lind et al., 1955). The lungs normally help cool the body by evaporation. Subjects will be less likely to continue wearing the respirator if body temperature is increasing (Laverne and Leyh, 1962). Subjects are more comfortable wearing respirators in situations where the inspired air temperature is lower than body temperature.

Increased core temperature is associated in an increase in ventilation, which will also contribute to the onset of fatigue (De V Martin, 1972). These conditions will also contribute to the onset of fatigue and mental error (Raven et al., 1979). The effect of heat stress will also contribute to the psychological feelings of claustrophobia.

Psychological Concerns

Enclosure of the face and head will precipitate reactions in susceptible subjects (Hodous, 1986). Some subjects will be unfit for respirator wear because of the psychological stress caused by the respirator. Morgan and Raven (1985) found that individuals with increased levels of trait anxiety, as measured by Spielberger's trait anxiety scale, were more likely to experience claustrophobia while working with a respirator. The Trait Anxiety test can be used to determine if a worker is psychologically fit to wear a respirator while working.

Pulmonary Factors Which Limit Work Capacity

Respiratory muscle fatigue has been proposed to limit exercise. This implies that fatigue of these muscles will occur prior to fatigue of other working muscles. Sheppard (1987) has suggested that the principle mechanism limiting ventilation during sustained exercise is dypsnea. He argues that the factors which contribute to the onset of dypsnea can be changed with training. These factors are: (1) desensitization to the feeling of heavy breathing (2) an increase in the strength of the respiratory muscles and (3) a decrease in the rate of accumulation of lactate (Sheppard, 1987).

Respiratory problems resulting from fatigue will occur at exercise durations of 60 minutes or more. The level of exercise which will elicit the 'breathlessness' response will decrease as exercise continues (Sheppard, 1987). It has been suggested that respiratory fatigue will ultimately decrease the available MVV (Freedman, 1970). This has been recently substantiated in a study by Loke and colleagues (1982), who found that MVV decreased 10% after a marathon.

The resultant decrease in MVV with prolonged exercise has been suggested to be caused by a number of factors. Cobley and coworkers (1981) found an increase in blood lactate during MVV and concluded that an increase in lactate production from respiratory muscles had resulted in the decrease in MVV. Other investigators (Moxham et al., 1980) found an exhaustion of glycogen stores in the sternomastoid muscle which correlated to respiratory fatigue. Neuromuscular fatigue (Knuttgen, 1984) and exercise induced bronchospasm (Mahler et al., 1981) have also been suggested as factors contributing to a decrease in MVV.

In 1970 Freedman investigated the ability of healthy subjects to sustain MVV for four minutes. He found that the average MVV4.0 was 129 liters/minute, with a range of 108-182 liters/minute. The average MVV4.0 represented 72% of MVV.25. Freedman's results are in agreement with the results of previous investigations (Shepard, 1967; Tenney et al., 1968; Clark et al., 1969). Freedman (1970) identified a maximum tolerable steady state ventilation of 102 liters/minute. This represents 80% of MVV4.0 and 64% of MVV.25. Using these percentages he concluded that 50% of the MVV.25 could be maintained during steady state, submaximal exercise for an indefinite amount of time.

Ventilatory drift is a progressive increase in ventilation during steady state exercise. At exercise levels greater than 60% of VO2max the increase in ventilation may be up to 30 liters/minute (Wiley et al., 1971; Cassidy et al., 1979; Dempsey et al., 1980). In individuals with a smaller lung capacity or diseased lungs (and therefore a decreased ability to move air in and out of the lungs) the MVV will not be compromised as greatly when wearing a respirator. These individuals, though, will also have a diminished ventilatory reserve. The increase in demand for ventilation as a result of ventilatory drift may cause these subjects to terminate work prematurely when wearing a respirator. Since vital capacity is related to body size, female subjects tend to have smaller lung volumes than males. This difference may be significant in assessing female workers for the ability to continue work at a given submaximal work level while wearing a respirator. Based on data collected both on female and male subjects we can predict, in women, that the decrease in MVV.25 (Raven and Wilson, 1989) resulting from the effect of the respirator will be less in subjects with greater body mass. The absolute lower MVV.25 values combined with ventilatory drift for an 8 hour work shift may cause endurance capacity and submaximal workload to be diminished enough to contraindicate work with a respirator. For example, a worker is being evaluated for an eight hour job with a ventilatory requirement of 40 l/minute. The work requires that a respirator be worn and the subject is found to have a MVV.25 of 90 l/minute with the respirator. According to Freedman (1970) the worker can sustain 50%, or 45 l/min for eight hours. If the effect of ventilatory drift is added to these values, the worker can barely meet the ventilatory requirement for the work.

In light of the research on the MVV and its relationship to the ability to sustain ventilatory demands, it is a good candidate for a clinical pulmonary function test which can be used to predict work performance while wearing a respirator.

Predictors of Work Performance While Wearing a Respirator

The need for objective methods to screen workers for the capability to wear a respirator while working is an issue of importance. Current federal regulations do require that a physician determine a worker's capacity for respirator wear. Many physicians are unfamiliar with the effects of respirators, and the physical demands of arduous occupations, such as firefighting. Currently, there are no proven guidelines for health workers or employing institutions to use when evaluating a worker's ability to wear a respirator while working.

In 1984 Harber and associates suggested using the ratio between the time of inspiration and the time of expiration to determine worker suitability for respirator wear. These investigators used both female and male subjects and a single respirator cartridge placed in the inspiratory limb of the breathing circuit to determine these results. They found that the ratio between Ti and Te showed consistent patterns of change (Ti increased and Te decreased) as resistance increased. Since the primary effect of respirator wear is its increase in resistance to breathing, this may be a good screening method. Unfortunately, even if the ratio between Ti and Te was found to correlate well to worker suitability for respirator wear, this method is not feasible for the mass screening of workers, and is not a simple test most physicians could perform with readily available equipment.

In 1981 Raven and coauthors investigated a number of pulmonary function tests for their ability to predict work performance while wearing a respirator. These investigators used both male and female subjects and a full face demand respirator. They found that the FVC could predict performance only for workers who did not achieve at least 90% of their age predicted norm for FVC. They also found that the MVV.25 decreased more while wearing a mask for subjects who had high MVV.25 scores. The resistance to breathing and its effect on the MVV.25 with the mask can be predicted according to these authors (Raven et al., 1981) by using the relationship:

$$\text{mask MVV.25} = \text{MVV.25} \times 0.49 + 28.9$$

This equation has a predictive value of 70%. Once the ventilatory requirement for a given work task has been determined the worker can be screened using the MVV.25 test. Then the MVV.25 value is used with the above equation to determine if the worker has the lung capacity for the work. If work is to be prolonged (>1 hour) then the additional ventilation required due to ventilatory creep must also be considered (Dempsey et al.,1977). Raven and coworkers (1981) suggested further study of the MVV.25 for evaluating worker suitability for respirator wear.

The MVV.25 test has been shown to be related to chest wall mechanics (Freedman, 1970). It is a simple, inexpensive test which can be performed in the office or even the field. It relates directly to respiratory fatigue and to the ability to sustain ventilatory demands (Freedman, 1970). The MVV.25 test can predict a workers ability to perform work with a respirator.

More recently MVV.25, FVC, and FEV1.0 have been proposed as choices for a clinical pulmonary function test to screen for capacity to wear a respirator (Wilson and Raven, 1989). To date none of these recommendations has been validated as a screening test. Using air line supplied, full facepiece, pressure demand respirators in both male and female subjects, Wilson and Raven (1989) examined seven clinical pulmonary function tests as possible predictors of ability to wear a respirator. Of the seven pulmonary function measures investigated, only the MVV.25 was able to predict maximal work performance. The relationship between MVV.25 with the face mask and that without the face mask was .92.

From the available research it appears that the MVV.25 test is the best candidate to predict worker suitability for respirator wear.

Chapter Three

METHODS AND PROCEDURES

This study used 15 volunteer female subjects between the ages of 18 and 40 years of age. Individual data for the physical characteristics of the subjects is shown in Appendix C. The subjects were not required to meet a minimum fitness level (VO2max). The subjects were required to sign an informed consent form and a medical history questionnaire prior to participating in the investigation (Appendices A and B). All of the testing was conducted at the Human Performance Laboratory on the University of Montana campus. There were three phases of testing.

Phase One: Pulmonary Function Tests

The first phase of testing included a battery of pulmonary function tests using a Multispiro spirometry system. The FVC, PEF, FEV1.0, and FEF25-75 measures were determined for each subject using this computer. The MVV.25 was measured using a 600 liter Gasometer. The MVV.25 measurements consisted of four trials on each subject. The first two trails were performed without wearing the respirator. The second set of trials were completed while wearing the respirator. The order of these trials was random.

During the MVV.25 trial with the respirator the subjects were instructed to apply pressure to the mask with the hands to ensure a good seal during the test. The subjects wore noseclips and adapted whatever posture they preferred. All of the subjects preferred standing. Subjects were given these instructions prior to the MVV trials and were encouraged to give maximum effort during the testing. The MVV was measured ad lib. This is contrary to the recommendations of some investigators who claim that the test should be standardized at a rate of 40 breaths per minute. If subjects are required to breathe at a set rate the MVV will most likely not reflect the subjects true maximum value. A maximum voluntary effort was needed in these trails, therefore, subjects were allowed to breathe at the rate and depth conducive to achieving a true maximum voluntary ventilation.

Repeatability analysis was carried out between the pulmonary function tests for all fifteen subjects. All data was extremely reliable having correlation coefficients greater than 0.9. The best score of the two trials was used in succeeding analysis. All pulmonary function test volumes were converted and reported in BTPS.

Phase Two: Maximum Graded Exercise Test Without Respirator

During the second phase of this investigation each subject performed a graded maximal exercise test on a Quinton motorized treadmill. The test protocol involved walking at a speed of 4 miles per hour (3.5 mph for 3 of the subjects) with a grade increase of 2.5% every 1 to 2 minutes based on the subjects fitness/activity level. Subjects continued this protocol until VO2max was reached. VO2max was determined by all of the following criteria:

1. An R value of 1.00 was attained.

2. The volitional fatigue of the subject.

These criteria were met in every subject for both the treadmill trails.

Subjects wore Nomex fire retardant pants and shirts. Subjects also carried a load of 24 lbs.in a Forest Service fire pack.

Expired gases were collected using a Beckman metabolic measurement cart calibrated with known gas concentrations prior to the onset of testing. The data collected from this analyzer included: $\dot{V}O_2$ (ml/kg/min), VO_2 (liters), VCO_2 (liters), FeO_2 and $FeCO_2$ (percent of O_2 and CO_2 in expired air), R (respiratory exchange ratio) and minute ventilation (l/min). Heart rate was monitored using telemetry (CIC Heart watch). Subjects were questioned every other minute of the test on their degree of breathlessness. They communicated this value by using a dyspnea scale (Morgan and Raven 1985). This scale is shown in Appendix D. The value of 1 indicated no breathlessness while 10 was considered extremely breathless work. Subjects were instructed that they could terminate the test at any time prior to completion, if such a need arose.

Phase Three: Maximum Graded Exercise While Wearing a Respirator

This section of testing was conducted as in phase two, except that the subject was wearing an air purifying respirator. The model used in this study was the COMFO II, manufactured by the Mine Safety Appliances Company. The mask was a half-faced rubber device which strapped over the head with a multiple strap yoke. The mask had a lower set of straps that went around the back of the neck. This ensured a good seal at the chin. This mask met the NIOSH (National Institute for Occupational Safety and Health) and the MSHA (Mine Safety and Health Administration) specifications for respirators. During the study the masks were equipped with two filter cartridges of the GMC-H type. These filters are high efficiency particulate filters (HEPA) which have been approved for respiratory protection against organic vapors, chlorine, hydrogen chloride, sulfur dioxide, chlorine dioxide, dust, fumes, mists, asbestos containing dusts, and mists. Canisters were changed after every four tests to insure a clean filter system and a minimum amount of inspiratory resistance.

Analysis of Data

Demographic Data

All data was analyzed on the University of Montana DEC System SPSSx, and Statistics with Finesse. Measures of central tendency and variablity were calculated to assess the mean, standard deviation and range of all independent and dependent variables.

Mask vs. No Mask

This data was analyzed using paired student t-tests comparing variables measured with and without the respirator. Submaximal and maximal oxygen consumption, ventilation, ventilatory threshold, and heart rate means were tested for significant differences between data collected with the respirator versus data collected without the respirator.

Correlation Matrix

The Pearson Product Moment Correlation was used to determine relationships between selected variables such as MVV.25, FVC, FEV1.0/FVC, FEF25-75, PEF, FEF25-75, heart rate, and VO2 to determine the relationships with such variables as the decrease in work capacity and the ventilatory threshold.

Multiple Regression

A multiple regression was conducted in order to determine which of the pulmonary function tests predicted the effect of the respirator on work capacity. The acceptable level of significance was $p<0.05$.

Chapter Four

RESULTS AND DISCUSSION

This chapter contains an analysis of the data collected from the pulmonary function tests, the VO2max test without the respirator and the VO2max test with the respirator. A discussion of the findings concludes the chapter.

Demographic Data

Descriptive data for the subjects is presented in Table 1. The means and standard deviations for age, height, weight and fitness level for the group are shown in Table 1. The group had a mean VO2max of 45 ml/kg/min. The minimum fitness requirement for firefighters in the U.S. Forest Service is 45 ml/kg/min. The subjects participating in the study were representative of the range of fitness levels encountered in the workplace. Individual data for the physical characteristics of the subjects is included in Appendix C.

Data for the pulmonary function testing is summarized in Table 2. There was a large range of values probably as a result of the wide range in age, weight, and height of the group (see Appendix C). With the exception of the MVV.25 test, the pulmonary function tests were performed without a respirator.

Respirator versus No Respirator

Table 3 shows the percent differences between the respirator and no respirator trials for a selection of variables. The MVV.25 was reduced an average of 25.19% for the fifteen subjects. Maximum minute ventilation (Vemax) was reduced an average of 17.8%, while VO2max was decreased an average of 12.6% with respirator wear.

The ventilatory threshold was determined by plotting oxygen uptake (VO2, L/min) versus minute ventilation (VE, L/min) as described by Astrand and Rodahl in 1986. One subject did not meet the criteria for VT (subject CS). Two other subjects (KF and BG) did not show a VT during the respirator trial. This is most likely because the subjects started the incremental exercise protocol at a rate and speed which was above the threshold.

The paired t-test measures for selected variables measured with and without the respirator are shown in Table 4. The difference between MVV.25 with and without the respirator was significant ($p<0.05$) as was the difference between VO2max, HRmax, rates of perceived exertion, and VT.

Heavy work is described by Astrand and Rodahl (1986) as requiring 40-60 L/min ventilation. At this level there were significant differences between the two trials for both VO2 (ml/kg/min) and VE. This represents the level of work which firefighters may be required to sustain in the field.

Correlations

Table 5 shows the correlations between selected variables. None of the pulmonary function tests were significantly related to work capacity (VO2max). Several of the pulmonary function tests correlated to the maximum minute ventilation, both with and without the respirator. The best correlates of VEmax without the respirator were: FVC, FEF, and FEV1.0. The best correlate of VEmax with the respirator was peak expired flow (PEF). The MVV.25 without the respirator correlated highly but not significantly to the 40-50 L/min ventilation while wearing the respirator.

Multiple Linear Regression Analysis

Using multiple linear regression analysis (Table 6), the %change in MVV.25 and PEF (peak expired flow) were found to predict VO2max while wearing the respirator (R=0.5131 and R squared = 0.3979). The best predictors of VO2max while wearing the respirator were the MVV.25 with the respirator, height, and weight (R=0.7556; R-squared=0.5710). VEmaxw/o was predicted using FEF (R=0.6144 and R squared = 0.3775). Using both FEF and FEV1 gave a better prediction equation for VEmaxw/o (R=0.6676 and R squared = 0.4457). Prediction of VEmax with the respirator was best using PEF, FEF and FEV1.0 (R=0.6308 and R squared = 0.3979).

Comparison Between Two Subjects

Table 6 is a comparison between two subjects of similar age, height, weight, and fitness levels. Both of these subjects are firefighters on U.S. Forest Service initial attack fire crews. Although the subjects are similar in most aspects, the MVV.25 and VEmax scores are not comparable. Subject T.T presents with a MVV.25w/o that is 39 L greater than B.G.; a MVV.25w that is 49 L greater than B.G.; a VEmaxw/o that is 27 L greater and a VEmaxw that is 27 L greater than subject B.G.'s.

Table 1

DESCRIPTIVE DATA FOR THE 15 SUBJECTS

Variable	Mean +/- Standard Deviation
Age (years) range 40-18	28 +/- 6.71
Height (cm) range 179-157	166 +/-7.31
Weight (kg) range 70-48	59 +/- 8.41
Fitness (VO2max) range 58-35	45 +/- 6.49

Individual data is included in APPENDIX C.

Table 2

MEANS FOR THE 15 SUBJECTS FOR THE PULMONARY FUNCTION TESTS

Variable	Mean	+/- Std. Dev.
MVVw/o (liters)	147	30
MVVw (liters)	110	26
FVC (liters)	4.04	.73
FEV1.0 (liters)	3.33	.59
FEV1.0/FVC (%)	83	6
PEF (L/s)	7.6	1.6
FEF25-75 (L/s)	3.4	.9

Note: w/o designates without the respirator, while
w designates with the respirator.

Table 3

% CHANGE BETWEEN RESPIRATOR AND NO RESPIRATOR TRAILS FOR THE 15 SUBJECTS

Variable	With Respirator	No Respirator	%Change
MVV.25 (L)	110.4	147.3	-25.19
VEmax (L/min)	77.5	94.9	-17.8
VT	18.9	21.2	-10.7
VE (40-50 L/min)	41.6	45.3	-8.2
VO2 at 40-50 L/min VE	25.4	27.5	-7.6
VO2max (ml/kg/min)	39.86	45.37	-12.6
Heart rate (bpm)	188	182	-3
VE/VO2 (max) (ml/kg/min)	2111	2006	-5
RPE	19.3	17	+12

VE/VO2 is the ventilatory equivalent found by dividing the VEmax by the VO2max. **RPE** is the score from the dypsnea scale; values were attained by adding the RPE scores

Table 4

PAIRED t-TEST VALUES FOR VARIABLES MEASURED WITH AND WITHOUT THE RESPIRATOR

Variable	T-Value	One-tailed significance
MVV.25	-9.011	.0001*
VO2max	-3.297	.0029*
VEmax	-4.65	.0004*
VE (40-50L/min)	-2.85	.0070*
VO2 at (40-50L/min VE)	-2.05	.0302*
HRmax	-3.51	.0022*
VE/VO2	-0.96	.1840
VT	-2.33	.0214*
RPE	1.36	0.099
DIw/0 & DIw	2.27	0.019*

VE/VO2 is the ventilatory equivalent in ml/kg/min found by dividing VE and VO2. **RPE** is determined by adding the subjects dypsnea score for the last four workloads. **DI** is the dyspnea index found by dividing the VEmax by the MVV.25. **VT** is the ventilation threshold.

* denotes values which are statistically significant ($p<0.05$)

Table 5

CORRELATIONS BETWEEN SELECTED VARIABLES

Relationship	r value	one-tailed significance
MVVw/o & MVVw	0.847	.0001*
MVVw & VO2w/o	0.195	.2465
MVVw/o & VO2maxw/o	-0.020	.4714
PEF & VEmaxw	0.437	.05*
PEF & VEw/o	0.253	.1887
PEF & VO2maxw	0.399	.0688
%Change MVV & %Change VO2max	0.379	.0802
%Change MVV & %Change VEmax	0.408	.0640
FVC & VEmaxw/o	0.535	.0191*
FEF & VEmaxw/o	0.632	.0056*
FEV1.0 & VEmaxw/o	0.668	.0033*
MVVw/o & VEw at 40-50 L/min	0.600	.0562
MVVw & VEw at 40-50 L/min	0.390	.0838

* denotes relationships which are statistically significant

Note: w/o designates without the respirator, while w designates with the respirator

Table 6

MULTIPLE LINEAR REGRESSION ANALYSIS FOR SELECTED DEPENDENT VARIABLES AND PREDICTORS

Predictor(s)	R	R-squared
VO2max with respirator:		
% change MVV.25 PEF	.5131	.2632
Height weight MVV.25(w)	.7556	.5710*
VO2max without respirator:		
MVV.25 w/o	.0197	.0004
VEmax with respirator:		
FEV1.0 PEF FEF	.6308	.3979*
MVV.25 w PEF	.5267	.2772*
VEmax without respirator:		
PEF FEF MVV.25 w/o	.6627	.4392*

* denotes significance at the $p<0.05$

Table 7

COMPARISON BETWEEN TWO SUBJECTS

Variable	T.T.	B.G.
Age (years)	26	23
Height (inches)	63	62
Weight (kg)	50	54.5
MVVw/o (L)	138	99
MVVw (L)	113	64
%Change MVV	-18	-32
VEmaxw/o (L/min)	115	88
VEmaxw (L/min)	103	76
VO2maxw/o (ml/kg/min)	58	51
VO2maxw (ml/kg/min)	55	45
%Change VO2max	-4	-11

Note: w/o designates without the respirator, while w designates with the respirator.

Discussion

The Effects of Wearing a Respirator

An important objective of this study was to determine what the effect of wearing a respirator would be on the work capacity of women. Work capacity was measured as the maximal oxygen consumption obtained during an incremental exercise test. Using this index of work capacity, the ability to do work while wearing a respirator was reduced (-12.6%, Table 3). This difference was significant (Table 4), and supports the second hypothesis indicated in Chapter One. In examining the individual VO2max data for the subjects it became apparent that individuals with values above 48 ml/kg/min were less impaired than individuals with values below this level. Subjects who achieved higher VO2max values were seemingly better able to adapt to the demands of the respirator. These subjects only showed 1-3 ml/kg/min decreases in VO2max.

These findings suggest that the current fitness standards in the U.S. Forest Service may need to be raised if respirator protection becomes mandatory. The current standard is 45 ml/kg/min. Based on the results of this study, fitness requirements for firefighting combined with the demands of respirator wear suggest that the fitness standard should be at least 48 ml/kg/min. Subjects who achieved this fitness level were able to attain a VO2max value of 45 ml/kg/min even while wearing the respirator.

The respirator was found to reduce the MVV.25 by an average of 25% (Table 4). This is in agreement with data from other investigations (Wilson and Raven, 1989; Raven et al., 1981). This also supports the first hypothesis noted in Chapter One ($p<0.0001$). The MVV.25 with the respirator was also highly correlated with the MVV.25 without the respirator ($R=0.847$; $p<0.001$). These results substantiate those of Wilson and Raven (1989) and Raven et al., (1981).

The maximal minute ventilation (VE, L/min) was also significantly impaired while wearing the respirator (-17.8%; p,.0004). This reduction in minute ventilation has been associated with a decrease in time to exhaustion during an endurance test (Craig et al., 1970). The resistance to both inspiration and expiration provided by the respirator is believed to be the primary mechanism causing the decrease in work capacity. The decrease in maximal minute ventilation also substantiates the conclusion that fitness standards may need to be raised if respirator protection becomes mandatory for wildland firefighting.

Other investigators (Raven et al., 1979) have shown that increased inspiratory resistance will decrease both submaximal oxygen consumption and submaximal minute ventilation. In this study submaximal VO2 was decreased 7.6% by the respirator and submaximal ventilation was decreased 8.2%. Thus, not only did the respirator decrease maximum oxygen consumption and maximal minute ventilation, submaximal values were significantly reduced as well. Since workers cannot sustain maximal values for long periods of time, these results may be an important consideration for employers involved in making decisions about respirator protection for employees.

At submaximal and maximal levels of minute ventilation and VO2, the respirator significantly impaired the levels attained. The amount of reduction appeared to be related to the volume of air, as ventilation increased the amount of decrement caused by the respirator also increased. This could be an important factor in deciding the degree to which the respirator will affect work performance at varying levels of work intensity.

The ventilatory threshold was also significantly reduced (-10.7%; $p<.0214$) by the respirator. The ventilatory threshold represents the upper limit of a sustainable workload, but will not be maintained in most individuals for more than 1-3 hours. The subjects also reached a higher dypsnea index ($\dot{V}Emax/MVV.25$) while wearing the respirator (Table 4). This indicates that the subjects were forced to "use a significantly higher proportion of their pulmonary reserve capacity" while wearing the respirator (Wilson et al., 1989).

The degree of breathlessness, which the subjects subjectively evaluated, was significantly higher during the respirator trial (Table 4). All of the subjects complained of the increased difficulty of breathing, at all workloads, while wearing the respirator. One subject became claustrophobic near the end of the test and removed the respirator prematurely. It has been speculated previously (Morgan and Raven, 1985) that some subjects may be unfit to wear a respirator due to psychological distress.

Claustrophobic feelings may be compounded by the effect of heat stress. None of the subjects in this study complained of heat stress while wearing the respirator. This may be due to the short length of the test (8-12 minutes). Other investigators (Raven et al., 1979) have proposed that the respirator may impose a heat stress. This heat stress can increase the core temperature and impose further demands on ventilation (Martin et al., 1979). Although heat stress was not a common complaint of the subjects, it may have been a factor. This factor could have been incorporated into the higher dypsnea scores while wearing the respirator.

Determining Who Can Work With a Respirator

The MVV.25 relates to lung and chest wall mechanics as well as to respiratory muscle fatigue (Tenney and Reese, 1968; Freedman, 1970). The MVV.25 also relates to sustained maximal exercise ventilation. MVV.25 values can increase up to 14% with endurance training (Shepard, 1982). Although the MVV.25 has been found to relate to the respiratory fitness of an individual, (Freedman, 1970) it is also influenced by other factors.

The MVV.25 is also correlated to body size and FEV1.0 (Freedman, 1970). The FEV1.0 will be dependent (in healthy subjects) on the vital capacity. During the MVV.25 test healthy subjects should be able to breathe one half of their vital capacity with each breath. Vital capacity is primarily determined by body size.

Four of the subjects in this study (TT, BG, SW, KS) were less than 64 inches tall. These four subjects each had a VO2max which was greater than 48 ml/kg/min. Their MVV.25w/o values ranged from 99 to 152 L/min. Five of the subjects (KM, MB, EM, CG, MP) who were taller (>64 inches) achieved VO2max values which were less than 48 ml/kg/min. These subjects all had MVV.25w/o values which were greater than 150 L/min. Individual data is shown in Appendix C. The influence of body size, therefore, probably prevented the MVV.25 score alone from being a good predictor of work capacity. When height, weight and the MVV.25 score were included in the regression analysis, a significant prediction equation was obtained (Table 6). The MVV.25 is a good predictor of work capacity when height and weight are considered. Other studies (Wilson et al., 1989) did not find a significant correlation between the MVV.25 with and without the respirator to performance time on an endurance test. These researchers, though, used both male and female subjects and did not account for body size.

Wilson and Raven (1989) found a significant correlation between peak expired flow and endurance time to exhaustion. PEF was also correlated to VO2max while wearing the respirator in this study, but this relationship was not statistically significant (R=0.379; Table 5).

Several pulmonary function variables were significantly correlated to maximal ventilation (Table 5). The best predictor of maximal ventilation with a respirator was the PEF (R=0.437; Table 5). Both the FEV1.0 and the PEF are pulmonary function tests which are affected by airway resistance during forced expiration. Any increase in resistance will decrease the ventilatory capacity. While wearing a respirator the increase in expiratory resistance will result in increased flow at the low flow, low lung volume portion of the ventilatory flow/volume loop. Thus, maximum minute ventilation will be decreased.

Actual decrements in ventilatory capacity could be predicted using a combination of pulmonary function tests: FEV1.0, PEF, FEF and the MVV.25. The best predictors of ventilatory capacity in this study were PEF, FEF and MVV.25w/o (Table 6).

Ventilatory requirements for given tasks have been determined. The oxygen requirement for wildland firefighters is 22-25 ml/kg/min (Jukkula and Sharkey, 1988).

The ventilation requirement for this level of oxygen consumption is 47-50 L/min (Astrand and Rodahl, 1986). In this study both the ventilation at approximately 47-50 L/min and the VO2 at this level of ventilation were significantly impaired by the respirator (Table 4). These submaximal levels are equivalent to those firefighters are required to maintain for prolonged periods. By using the FEV1.0, PEF, and FEF to predict VEmax one could determine whether an individual had the ventilatory reserves for sustained work with a respirator.

Freedman (1970) found that 50% of the MVV.25 could be maintained for long periods of time. The mean MVV.25(w) value for this group of women was 110 L/min (Table 2). Dividing this in half (55), it becomes apparent that on the average, individuals in this group could barely sustain the 47-55 L/min ventilation requirement while wearing the respirator. This estimate, though, does not account for the ventilatory drift during exercise. Ventilation may drift up to 30L/min during sustained exercise (Dempsey et al., 1977). With this additional ventilatory requirement, the group as a whole does not possess the pulmonary reserves necessary to do sustained work with a respirator.

Subject BG (Table 7) in this study is an experienced firefighter on an initial attack fire crew. This subject achieved a VO2max of 50.5 ml/kg/min, indicative of excellent physical fitness. This subject is small (62 inches tall) and achieved very low MVV.25 values both with and without the respirator. The MVV.25 with the respirator was 64 L/min. One half of this, 32 L/min falls well below the 47 L/min ventilation requirement. Although BG is in excellent physical condition her small stature and lung volumes may prevent her from being able to do prolonged work with a respirator.

Another subject in this study (TT), also an experienced firefighter, and smaller in stature (63 inches), had an MVV.25 with the respirator of 113 L/min (Table 7). One half of this MVV.25 (56.5) makes the subject marginally acceptable for respirator work on the basis of ventilatory requirements. These two subjects exemplify that some female subjects, although, in excellent physical condition may be unsuitable for respirator wear. The small stature of these subjects is probably dictating the lower lung volumes and lack of reserve pulmonary capacity necessary for doing work with a respirator.

Chapter Five

Summary, Conclusions and Recommendations

The preceding chapters have presented the problem, its significance, the review of related literature, the methodology of the study, statistical analysis of the data, and a discussion of the results. This final chapter summarizes and draws conclusions about the study. Lastly, this chapter makes recommendations about future research pertaining to the use of respirators for wild land firefighting.

Summary

The focus of this study was to determine the effect of air purifying respirators on the work capacity and pulmonary function of female subjects. Fifteen subjects between the ages of 18 and 40 underwent a battery of pulmonary function tests. Subjects then performed two graded maximal oxygen consumption tests to exhaustion, one with the respirator and one without.

The results of this study showed that the respirator significantly decreased VO2max (12.6%). The respirator also significantly decreased the MVV.25 (25.2%), VEmax (17.8%), ventilatory threshold (10.7%), ventilation at 40-50 L/min (8.2%), and VO2 at a ventilation of 40-50 L/min (-7.6%). During the respirator VO2max trial some subjects complained of claustrophobic feelings and one subjected terminated the test prematurely. At all workloads the rates of perceived exertion were higher while performing the treadmill work with the respirator.

Another objective of this study was to determine if women would possess the ventilatory reserves necessary to do work with a respirator. Based on the average MVV.25 while wearing the respirator, the group was marginally able to maintain an adequate level of ventilation. Some of the smaller subjects, although achieving excellent fitness levels based on the VO2max score, would be considered unable to do work with a respirator when considering the MVV.25 score with the respirator.

The last objective of this study was to find a method of predicting the ability to do work with a respirator. The MVV.25 with the respirator along with height and body weight provided a regression equation which could predict the VO2max while wearing the respirator (R=.7556;R-squared=.5710).

Conclusions

Based upon the analysis of the data collected from a sample population of fifteen female subjects, of varying levels of fitness, from the community of Missoula, Montana and within the limitations of this study, the following conclusions were drawn:

1. The effect of wearing a respirator during an incremental exercise test to exhaustion on female subjects is: a 12.6% decrease in VO2max; a 25.2% decrease in MVV.25; a 17.8% decrease in VEmax; a 10.7% decrease in the ventilatory threshold; an 8.2% decrease in the ventilation at 40-50 L/min; a 7.6% decrease in the VO2max at the 40-50 L/min level of ventilation; and increased feelings of dypsnea. These results suggest that the fitness requirements for forest fire fighters may have to be raised if respirator

protection becomes mandated.

2. The MVV.25 while wearing the respirator along with the height and weight of a subject was the best predictor of the VO2max while wearing the respirator.

3. If the ventilatory requirements of a job are known, the MVV.25 score while wearing the respirator could determine if a worker had the pulmonary capacity to do the work. The MVV.25 is halved and as long as this value is approximately 20-30 L/min above the ventilatory requirement for the job the individual is deemed capable of doing the work while wearing the respirator. The additional 20-30 L/min is to allow for the ventilatory drift which may occur during an eight hour shift (Tenney and Reese, 1968).

4. Based on the conclusions stated in 2 and 3 above, decisions by employing agencies about the ability to do work while wearing a respirator should be able to be formulated in an objective manner.

5. The MVV.25 can increase up to 14% with endurance training (Shepard, 1982). The MVV.25 is also highly correlated with body size (Freedman, 1970). Such that women of smaller stature, though, in excellent physical condition, may not have the pulmonary reserve capacities to meet ventilatory requirements while wearing a respirator.

Recommendations for Further Research

The following suggestions for further research were prompted by this study:

1. A study using women should be conducted using an endurance protocol. An endurance test lasting 60-120 minutes at approximately 40-50% VO2max may provide a setting more comparable to that found outside of the lab. Such a study could provide further insight into the effect of respirators on work capacity in women. Such a study could be performed to exhaustion and standardized by keeping ventilation or heart rate at a constant rate by adjusting the speed or grade of the treadmill.

2. There is a need to study the effect of wearing a respirator in an hypoxic environment in both men and women. This is pertinent to forest firefighters since some forest fires are fought at elevations greater than 8000 feet (especially in Colorado and California).

3. Heat stress can increase ventilation. The effect of the respirator on heat stress, in addition to being in a hot environment, needs to be studied. The results of such a study may be important in making the final decision about fitness standards for firefighters who may be required to wear a respirator.

4. There is a need to further investigate the MVV.25 as a predictor of work capacity in women. Although this test seemed to be able to predict the VO2max while wearing the respirator, some subjects in actuality may not possess the pulmonary reserve capacity to do work with a respirator. Such a study should involve a small sample of women with excellent fitness levels but with low lung volumes. These women should be tested in an environment which closely mimics the real job situation. Such a study could provide

valuable data about the ability of women to sustain work while wearing a respirator, and about the MVV.25 as a pulmonary function test to predict this ability.

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APPENDIX A
HUMAN INFORMED CONSENT FORM

Informed Consent

This study will investigate the effect of respirator wear on work capacity and pulmonary function in female subjects. The results of this research will provide important information about the effects of wearing air purifying respirators as well as determining an objective measure of a person's ability to wear a respirator while working.

Participation in this research will include two graded, maximal exercise tests. One of these tests will be performed with the respirator, the other without. The two graded, maximal exercise tests will not be performed on the same day. The duration of each test will be between 10 and 15 minutes. Expired air will be collected and analyzed throughout the test. Heart rate will be monitored using a CIC heart watch. In addition, subjects will undergo a series of clinical pulmonary function tests. These tests will be performed in duplicate both with the respirator and without the respirator.

There is a possibility that certain abnormal responses could occur during the tests. These include an abnormal blood pressure, 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, the subjects will gain an assessment of their fitness level. Subjects will also gain knowledge about their pulmonary function. All measurements and parameters, and how they relate to the subject will be discussed with each participant.

Individuals trained in exercise physiology and CPR will be assisting in the tests. If subjects experience any discomfort (such as leg cramps, dizziness or severe fatigue) they may stop the test. Any further questions may be addressed to Tara Townsend (728-5706) or through the University of Montana Department of Health and Physical Education.

As a subject participating voluntarily, I am free to withdraw from this study at any time of my choosing. Confidentiality will be maintained in any published materials, and in any data analysis.

"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 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 Tara Townsend, and such assistants as she 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

MEDICAL QUESTIONNAIRE

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

<u>Yes</u>	<u>No</u>	
----	----	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 exercised induced asthma?
----	----	Do you have any restrictive or obstructive lung problems?

If you have answered no to all of these questions, you have reasonable assurance of suitability for this study.

APPENDIX C

PHYSICAL CHARACTERISTICS OF THE FOURTEEN SUBJECTS.

SUBJECT	AGE(YRS)	HT(IN)	WT(KG)	VO2max	MVV.25(L/min)
TT	26	63	50	57.5	138
CD	20	66	65	44.7	123
KM	39	67	68	40.2	168
MB	28	70.5	69	44.4	168
KF	26	70	65	43.2	150
EM	25	64	70	38.3	169
JM	23	67	57	55.9	162
BG	23	62	54.5	50.5	99
CG	18	70	63	43.1	209
CS	34	64	50	37.6	123
SW	34	64	53	47.8	152
KS	34	64	48	51.4	151
SH	23	62	50	35.7	103
MP	29	67	63	43.3	173
TG	40	63	50	47.0	122

APPENDIX D

DYSPNEA SCALE

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

This scale was used to rate the subjects' degree of breathlessness. A score of 0 indicated no breathlessness while a score of 10 indicated maximal breathlessness.

APPENDIX E

Photo of Subject Performing a Treadmill Test While Wearing a Respirator

APPENDIX F

Photo of a Subject Performing Pulmonary Function Test