SAM-TR-66-4

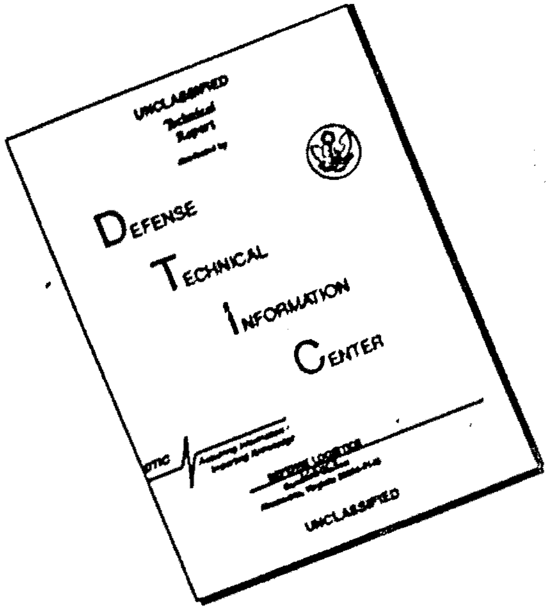
REDUCED BAROMETRIC PRESSURE AND RESPIRATORY WATER LOSS

EDWARD C. WORTZ, Ph.D., et al.

February 1966

USAF School of Aerospace Medicine
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

REDUCED BAROMETRIC PRESSURE AND RESPIRATORY WATER LOSS

EDWARD C. WORTZ, Ph.D.
ROBERT A. DIAZ
FREDERICK H. GREEN, B.A.
WARREN G. SANBORN, B.S.
DAVID K. EDWARDS III, B.S.
EDMUND J. PRESCOTT, Ph.D.
GILBERT R. SCHERER, M.D.

FOREWORD

This report was prepared in the Department of Life Sciences, AiResearch Manufacturing Company, Los Angeles, Calif., under contract No. AF 41(609)-2389 and task No. 793002. It was monitored by Captain William G. Robertson, Environmental Systems Branch, USAF School of Aerospace Medicine. The paper was submitted for publication on 15 November 1965. The work was accomplished between 1 April and 31 October 1964.

The scientific contributions of T. J. Harrington, J. N. Waggoner, and L. E. Browne, and the technical assistance of N. J. Belton, W. S. Schreck, V. G. Gettemy, R. Godson, and E. Maltby are gratefully acknowledged.

The tympanic thermocouple was provided by Dr. T. H. Benzinger, Naval Medical Research Institute, Bethesda, Md.

This report has been reviewed and is approved.

Harold V. Ellingson

HAROLD V. ELLINGSON
Colonel, MC, USAF
Commander

ABSTRACT

Respiratory water loss was investigated with a group of normal subjects breathing oxygen orally. Data were collected from all subjects under three absolute pressures (3.5, 7.0, and 14.7 p.s.i.), three work rates on a treadmill (0, 2, and 4 m.p.h.), three humidities of the inspired oxygen (40° F., 60° F., and 80° F. dewpoint), and three drybulb temperatures of the inspired oxygen (95° F., 75° F., and 55° F.). The data were analyzed statistically.

All of these variables affected respiratory water loss in varying degrees. Reduced pressure diminished respiratory water loss, apparently because of a corresponding decrease in minute volume observed at lower pressures. Increased work rates elevated pulmonary ventilation and thus increased respiratory water loss. Increasing humidity decreased water loss, while increasing drybulb temperature produced greater water loss. Expired gas temperatures approached body temperature only at elevated inspired temperature; the expired gas volume was never saturated.

NOMENCLATURE

ATP	Ambient temperature and pressure.
ATPD	Ambient temperature and pressure, dry.
BMR	Basal metabolic rate.
BSA	Body surface area.
BTPS	Body temperature and pressure, saturated.
D.B.	Drybulb temperature, degrees Fahrenheit.
D.P.	Dewpoint temperature, degrees Fahrenheit.
N.S.	Not significant.
ΔP	Delta pressure; pressure drop.
P/DP	Interaction between pressure and dewpoint significant at the probability level indicated.
p.s.i.	Absolute pressure, pounds per square inch.
r	Coefficient of correlation.
RSS	Root sum square.
STP	Standard temperature and pressure.
W.R.	Work rate, miles per hour treadmill speed.
WR/DP	Interaction between work rate and dewpoint.
WR/P	Interaction between work rate and pressure.

REDUCED BAROMETRIC PRESSURE AND RESPIRATORY WATER LOSS

I. INTRODUCTION

The general purpose of the research described in this report was to ascertain and quantify the factors influencing the rate at which water is removed from the body by respiration. The term *respiratory water loss* is used throughout this report to denote water transferred from the body during respiration—i.e., the difference between the water vapor content of the inspired and the expired gas. In particular, this work investigated the effects of pressure, inhaled dewpoint temperature, inhaled drybulb temperature, and work rate on respiratory water loss, for subjects breathing oxygen by mouth.

The results of this research are considered pertinent to normal pulmonary physiology and water balance at sea level as well as at high altitude; the data have specific application to problems associated with space flight, where problems of material balance are critical.

Several previous studies are related to this experiment. The earlier studies have been adequately summarized by Newburgh and Johnston (1). In 1904 Foá (2) suggested that water loss from the lung is reduced at high altitudes, and Guillemard and Moog (3) in 1910 came to the same conclusion after observations made in the mountains. Galeotti (4) observed total expired water rates of 0.0326 gm./liter, with 0.0292 gm./liter added during respiration, for subjects breathing air at 12.5° C. and 30% relative humidity. He also found that increasing the inspired humidity to 68% reduced the total expired water to 0.0322 gm./liter and the water loss to 0.0247 gm./liter. Further, he suggested that increasing the inspired temperature would lessen the water loss. In a later work, Galeotti (5) stated that expired air was 90% saturated.

Benedict and Benedict (6) in 1927 observed rates of water loss ranging from 0.1467 to 0.2008 gm./min. for subjects breathing dry oxygen at basal metabolic levels. These figures approximated 40% of the total insensible water loss under the test conditions. In 1930 Jores (7) reported essentially the same results as Benedict and Benedict.

In 1934 Adachi and Ito (8) corroborated Galeotti's 1912 work (4) when they found that increasing inspired relative humidity reduced the respiratory water loss. They observed a respiratory water loss of 0.0962 gm./min. for subjects breathing air.

In 1945 Burch and Winsor (9) reported an average respiratory water loss of 0.179 gm./m.^{2} of BSA per minute for subjects breathing oxygen with their "waterless-type" BMR device. Their conclusion was that more than 50% of the total insensible water loss came from the lungs; this value is considerably higher than the estimates made from earlier experiments.

Newburgh and Johnston (1) stated that water loss from the lung is controlled simply by the physical conditions of the environment and by lung ventilation—i.e., minute volume. Since their work, Thauer et al. (10) in 1955 established that other factors, such as the total time that the ventilating gas spends in the lung and the effects of the respiratory "dead space," are extremely important in regulating water loss. According to the interpretation of these investigators, at the end of expiration the respiratory tract is filled with unexpired gas which has more or less the same composition and physical properties as alveolar gas; this is the air mass which they called the respiratory "dead space." The respiratory dead space affects the transfer of water vapor because its presence implies that not all the tidal inflow to the lung surface is ambient external air. Thauer et al. found an effective change in alveolar water vapor concentration owing to the presence of this dead space. These investigators postulated from their work that, at the end of inspiration, the temperature of the air in the respiratory tract is somewhat lower than body temperature, if it is assumed the inhaled air is at a temperature below 37° C., and that some of the water vapor from the lungs condenses in the respiratory tract upon expiration. Hence, the total amount of water lost in respiration is a function of the dead space in the pulmonary tree and its interaction with the other pertinent physical and physiologic factors.

It is often stated that the expired air leaving the lung is saturated with water vapor at body temperature. Thauer et al. (10, 11, 12) have shown, however, that this is not the case and that the expired air under normal conditions is very seldom saturated. Nevertheless, they found that a significant amount of water vapor transfer does occur during respiration, and that this amount is definitely a function of water vapor in the inspired air.

There are differing opinions as to whether expired air is saturated. Pfeiderer and Less (13), Corlette (14), and Buettner (15) conclude that expired air is saturated. On the other hand, Seeley (16), Christie and Loomis (17), Burch (18), and McCutchan and Taylor (19) conclude that expired air is unsaturated. McCutchan and Taylor found expired relative humidities of 80 to 90%. Seeley reported 80% expired relative humidities at 70° F. inhaled drybulb temperature. He also reported that, for cold temperatures, the expired relative humidity is always 80 to 90%, regardless of the inhaled relative humidity.

An examination of tables of water vapor pressure (steam) shows that the amount of water vapor which can be carried by a given volume of gas is dependent to a large extent on the drybulb temperature of that gas. This general physical principle is pertinent to studies of water vapor transfer occurring through respiration.

McCutchan and Taylor found that the drybulb temperature of expired gas is indeed a function of the drybulb temperature of the inspired gas. Consequently, the mean temperature of that air occupying the lungs after inspiration is dependent on the temperature of the inspired air. According to their data, when dewpoint is held constant and the temperature of the inspired air is increased, an increase occurs in the exhaled water vapor pressure. Although most of their data is for high temperatures (greater than 100° F.), their general observation that the exhaled temperature and relative humidity are determined by the inspired temperature and humidity is in agreement with the observations of Burch (18), Loewy and Gerhartz (20), Pfeiderer and Less (13), and Seeley (16). McCutchan and Taylor report no relationship between respiratory volume and inspired wetbulb temperature.

Marshall and Specht (21) measured respiratory water loss at reduced pressure (226 mm. Hg) and at sea level (760 mm. Hg) by use of two methods concurrently. The first method involved the freeze-trapping and weighing of the expired water; this method had several limitations, recognized by the authors, including the necessity of assuming the quantity being measured and the use of volume correction technics whose implicit errors masked the small changes in water weights. The second method employed a dewpoint measuring device consisting of a copper bar, instrumented with thermocouples, along which a thermal gradient was maintained; this technic was hampered by numerous technical difficulties caused in large part by the crudity of the apparatus.

The results reported by Marshall and Specht were obtained by computations whose precise nature is unclear; separate calculations were made from the measured dewpoints and from water weights per liter on the basis of exhaled volume corrections that were made to standard pressure and assumed conditions of partial saturation. These results all indicated a reduced water loss with reduced pressure. Their data also demonstrated a significant decrease in minute volume with altitude, a phenomenon which may have been brought about by a decreased respiratory rate, and which seemed to cause the observed decrease in respiratory water loss at altitude. The vapor pressure calculations employed by these authors indicate an apparent increase in expired water vapor pressure at altitude when volume corrections were made to standard conditions, although the dewpoint calculations indicated a decrease in vapor pressure. Even with the calculated increase in vapor pressure with altitude, however, the reduced respired volumes were sufficient to decrease the total respired water loss.

II. METHODS AND PROCEDURES

Experimental design

The present experiments were designed to test the effects of pressure, inhaled drybulb temperature, inhaled dewpoint temperature, and work rate on the rate of respiratory water loss. Three levels were employed for each of these parameters as follows:

1. Pressure: 3.5 p.s.i., 7.0 p.s.i., and ambient barometric (14.7 p.s.i.).
2. Inhaled drybulb temperature: 55° F., 75° F., and 95° F.
3. Inhaled dewpoint temperature: 40° F., 60° F., and 80° F.
4. Work rate: rest (0 m.p.h.), 2 m.p.h., and 4 m.p.h. level treadmill speed.

Because of the physical impossibility of high inhaled dewpoint temperatures at lower inhaled drybulb temperatures, a strictly orthogonal experimental design could not be employed. The combinations of the independent variables which formed the experimental conditions employed are illustrated by the three matrices shown in figure 1. Each of these matrices represents a different level of inspired dewpoint temperature. Five subjects were employed in the experimental program, and each subject was tested under all of the conditions represented by each cell in the three matrices. The sequence of inhaled drybulb and inhaled dewpoint combinations were randomized for each subject. The sequence of pressure changes and work rates, however, was systematic for a given set of inhaled drybulb and dewpoint conditions. This systematic sequence is described under test protocol later in this section.

The dependent variables were expired dewpoint temperature, expired drybulb temperature, expired absolute pressure, respired volume, heart rate, respiration rate, rectal temperature, tympanic temperature, and nine skin temperatures.

Test apparatus and procedures

Altitude chamber. The respiratory water loss tests were conducted in a low-pressure altitude chamber used specifically for physiologic research. The chamber has an internal volume of 750 cu. ft. and is equipped with a 250 cu. ft. airlock. Communications with chamber occupants are maintained throughout each test by means of an aircraft-type low-impedance intercom system. The chamber also is equipped with an oxygen supply for the test observers' masks and with an emergency oxygen supply consisting of pressurized "walk-around" bottles which can be attached to the masks. The mechanism used to induce the various desired metabolic loads on the test subjects is a variable-speed level treadmill situated in the chamber so that a minimum length of ducting is required in the breathing circuit.

Environmental control system. The altitude chamber was equipped with an environmental control system designed specifically for this experiment. The system was designed to condition a desired mass of gas to specified drybulb temperatures and water vapor pressures within narrow limits over a wide range of flow, temperature, and relative humidity. The conditioned inspired gas was monitored extensively and held within ±2.0° F. drybulb and ±2.0° F. dewpoint. To obtain these conditions, cryogenic oxygen was vaporized and ducted through a pressure regulator to a saturation chamber for aqueous saturation at a high temperature. The supersaturated gas then passed through the primary gas-to-liquid heat exchanger, where it was cooled and a portion of the water vapor condensed and trapped, so that the emerging gas was at the desired saturation temperature or dewpoint. From the primary heat exchanger, the gas passed through a reheater to attain the desired dry bulb temperature, then on through one of two variable-area flowmeters. The gas exiting the flow-measuring section was then ducted through the chamber bulkhead, directly to the secondary gas-to-liquid heat exchanger, which was used for final adjustment of the dewpoint of the inspired gas. From the secondary heat exchanger, the gas was ducted to a temperature-controlled plenum chamber and exhausted into

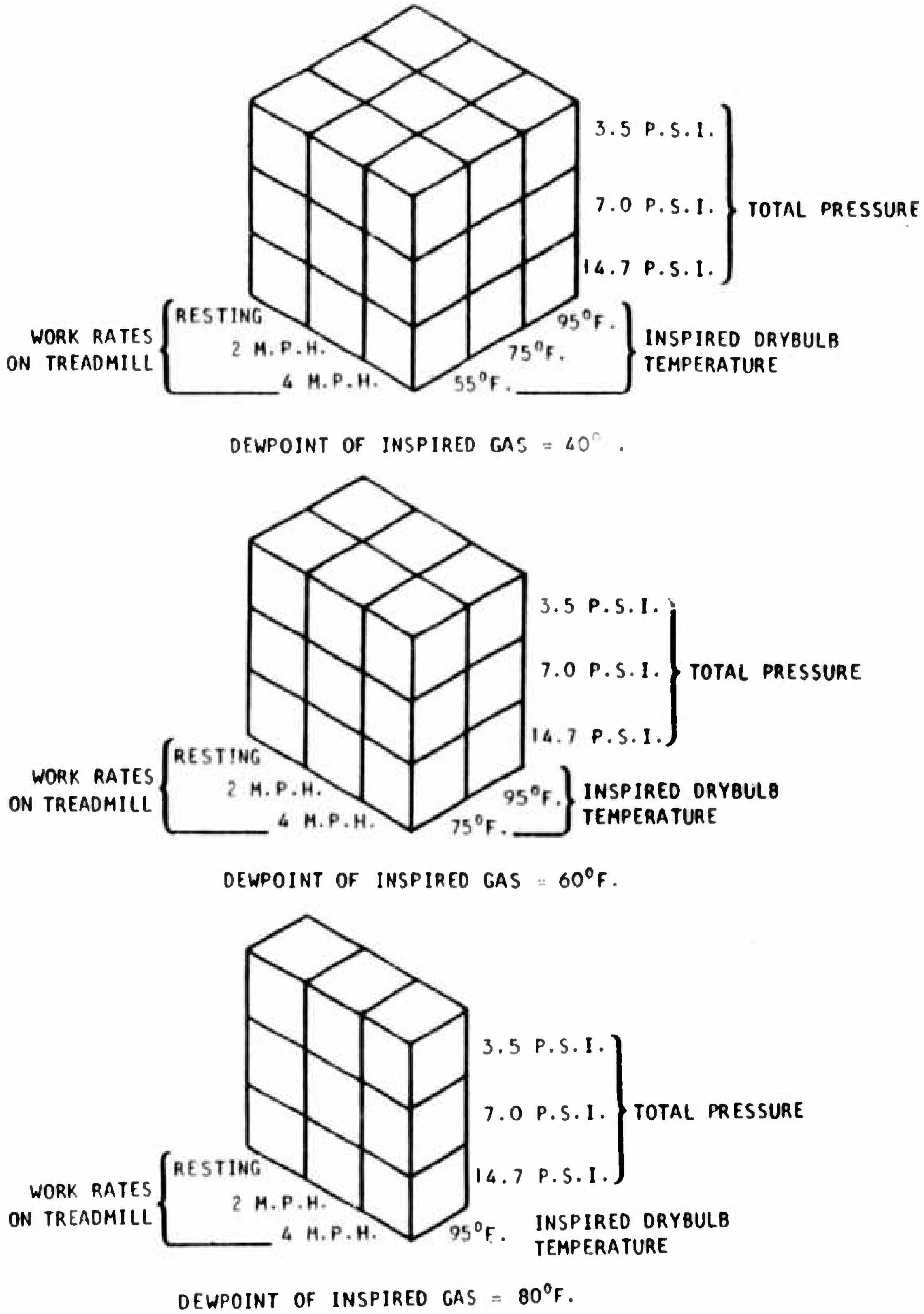


FIGURE 1

Experimental design.

the altitude chamber. Temperature-controlled, flexible, convoluted hoses connected a bifurcated mouthpiece to the plenum chamber. The hoses were wrapped externally with high-resistance heating tapes and liquid-coolant tubes, with evenly spaced intervals between the heating tapes and coolant tubes. The independently controlled heating tapes and coolant lines were used to maintain a precise inspired drybulb temperature and to prevent condensation of water vapor within the inspiration and expiration hoses.

The bifurcated mouthpiece was formed in two halves made of free-machining brass, 0.030 in. thick, and plated with gold (MIL-G-45420), 0.010 in. thick, to minimize radiant heat transfer. The mouthpiece also was wrapped with independently controlled heating tapes and coolant tubes so that the inspiration and expiration systems could be maintained at the proper temperatures up to the mouth. An epoxy septum formed a leakproof bond of the two halves and separated the inspiration and expiration systems, thus minimizing thermal conduction between the two systems at the portal of the mouth. This permitted an accurate determination of the true physical conditions of the inspired and expired gases. An external and exploded view of the bifurcated mouthpiece can be seen in figures 2 and 3.

Upon inspiration, a low-pressure-drop inspiration check valve in the mouthpiece (pressure drop less than 0.5 in. of water) opened and allowed the conditioned gas to flow from the plenum chamber into the mouth on demand. Upon expiration, the inspiration check valve closed and the low-pressure-drop expiration check valve (pressure drop less than 0.5 in. of water) opened, thus allowing the expired gas to flow from the bifurcated mouthpiece, through this temperature-controlled, flexible hose, to the respiration gas meter for volumetric measurements. After the measurement of the expired gas volume, the gas was returned to the plenum chamber through the return port, at a distance approximately 2 ft. downstream of the inspired gas port, and exhausted into the altitude chamber. The volume of gas flowing through the plenum chamber (4 cu. ft./min.) exceeded even the strongest inspiration; therefore, the ventilated volume of preconditioned gas through the plenum chamber never reached zero, and the expired gas was continually washed out of the plenum. Both the inspired and expired gas systems were connected to the plenum chamber to prevent a pressure drop across the two systems, thus preventing a "forced" opening of the inspiration and expiration check valves in the bifurcated mouthpiece.

A detailed schematic diagram of the respiration circuit is shown in figure 4.

Drybulb measurement. The inspired and expired gas drybulb temperatures were measured independently at the mouth and also just beyond it. Two microminiature thermocouples were located just within the mouthpiece, one on each side of the septum, at the mouth, to measure the exact temperature of the gas entering or leaving the mouth. The thermocouples had a response time of 10° F./sec. and an accuracy of ±0.2° F. They were connected to a water- and ice-bath reference junction, and the temperatures were recorded on an Offner Type S Dynograph with an expanded temperature scale for greater accuracy. The temperatures also were used to correlate respiration rate with the opening

FIGURE 2

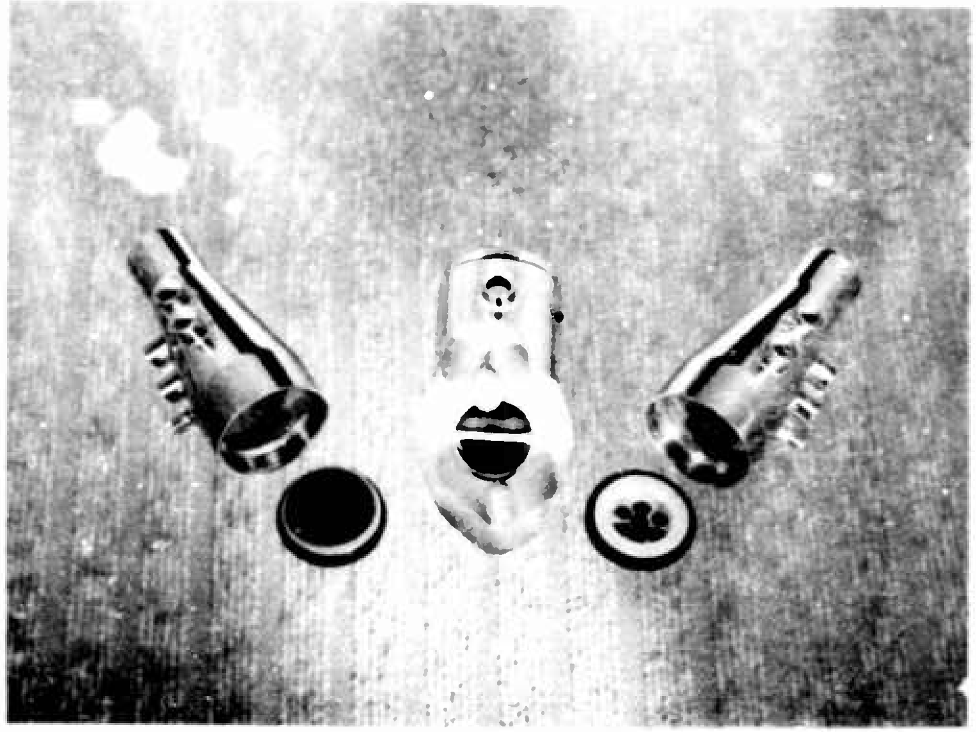


FIGURE 3

Bifurcated mouthpiece.

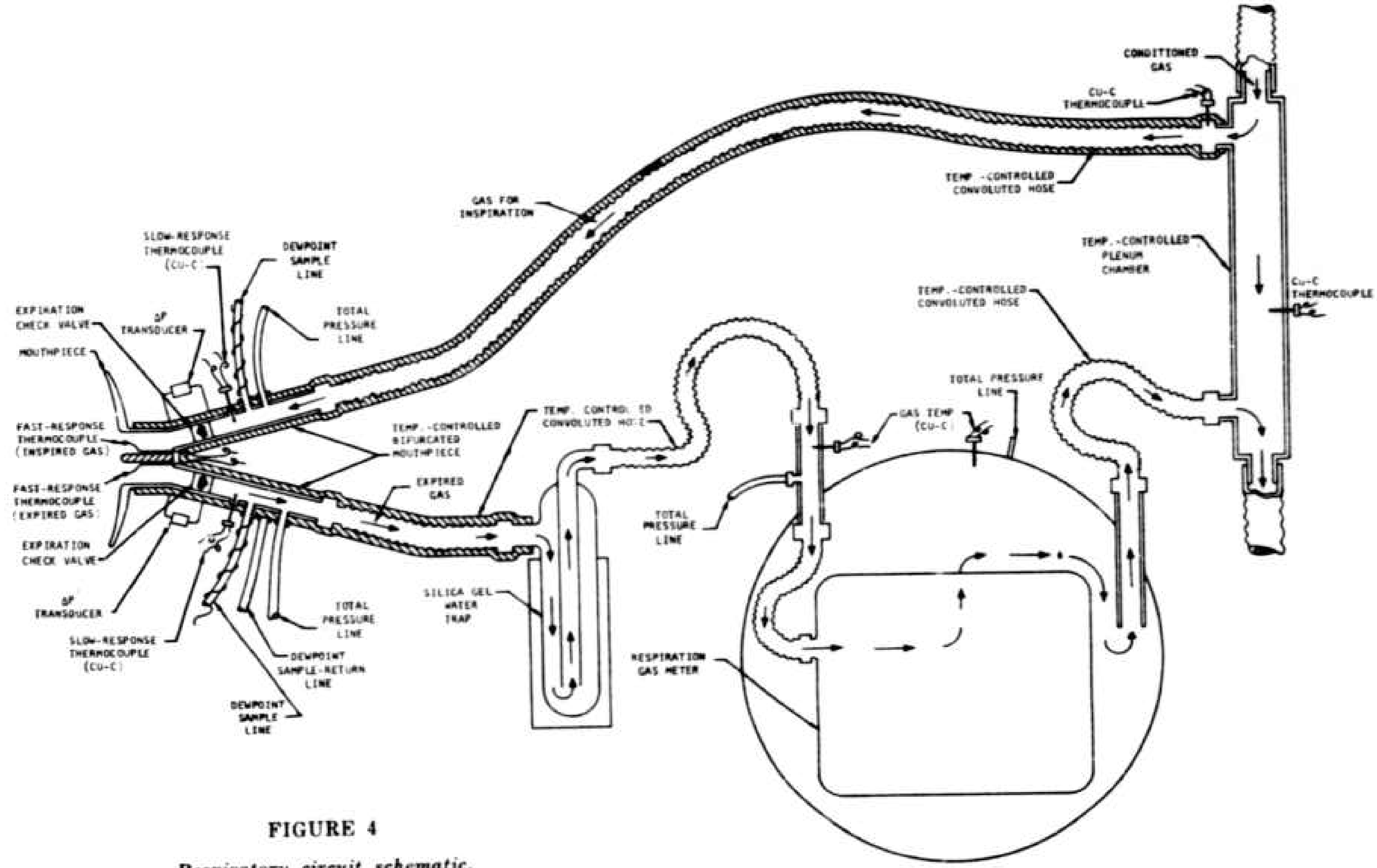


FIGURE 4

Respiratory circuit schematic.

of the inspiration and expiration check valves. Two copper-constantan, slow-response thermocouples were located upstream and downstream of the inspiration and expiration check valves, respectively, as a backup and a cross-check of the rapid-response thermocouples. These two were connected directly to a Honeywell-Brown Electronik strip chart recorder and were monitored periodically.

Dewpoint measurement. A small portion of the inspired and expired gases was picked up at the bifurcated mouthpiece, upstream and downstream of the inspiration and expiration check valves, respectively, and ducted through heated stainless-steel lines to their respective dewpoint instruments. In the case of the expired gas, the dewpoint sample was returned to the expiration system so that the volume measurement of the expired gas was not affected. The inspiration dewpoint sample was returned to the altitude chamber, but not to the inspiration gas system, since it was taken from upstream of the inspiration check valve.

The inspired and expired dewpoints were measured independently with an accuracy of ±0.5° F. by two AiResearch-built instruments. A gas sample was picked up at the bifurcated mouthpiece as described above, and ducted through heated lines, through the altitude chamber bulkhead to the dewpoint instrument. The gas sample entered the heated dewpoint cell and passed over a heated glass-chromium mirror mounted on a copper base which extended into a methanol and Dry-Ice heat sink. A controlled reduction in the amount of electrical current passing through the heating element of the mirror-copper base reduced the surface temperature of the mirror, thus causing dew to form on it at the water-vapor dewpoint temperature. Light from an incandescent source inside the sample cell was reflected away from the microscope by the mirror until refraction occurred from dew formation. The light reflection then was detected instantaneously by visual observation through a four-power microscope mounted on the sample cell. The mirror surface temperature was sensed by a copper-constantan thermocouple, embedded 0.001 in. beneath the surface of the mirror. The thermocouple leads were connected to a water- and ice-bath reference junction. From the reference junction, the thermocouple signal was conducted as a millivolt potential through two copper wires to a two-pen Honeywell-Brown Electronik recorder. An increase in the amount of electrical current passing through the heating element of the mirror-copper base raised the surface temperature of the mirror immediately, and the dew was vaporized, thus leaving the instrument ready for dewpoint measurement of another sample. The gas sample leaving the heated dewpoint cell passed through a variable-area purge meter, and then through a diaphragm pump for return to the respiration systems. Each of the two (inspired and expired gas) dewpoint instruments was connected to one of the two pens on the recorder. Trained personnel were able to operate the dewpoint instruments reliably with an accuracy of ±0.5° F. and a reproducibility of ±0.25° F.

Total pressure measurement. Inspiration and expiration gas pressures were measured at the bifurcated mouthpiece by absolute-pressure, mercury manometers. The manometer pressures were corrected for temperature effects periodically during each test. Also, the openings and closings of the inspiration and expiration check valves were monitored by using two H_2O ΔP transducers (0 to

1 in.), one across each check valve. The signals from these transducers were recorded on an Offner Type S Dynograph and were used in conjunction with a respiration strain gage, placed around the subject's chest, in determining his respiration rate, as well as for correlating the inspiration-expiration temperature profiles. Figure 4 indicates the location of the total pressure lines. Figure 5 shows a subject in position for testing, with the ΔP transducers and the respiration strain gage visible.

Expired water vapor trap. After the physical conditions of the expired gas were determined at the mouthpiece, the gas was ducted through a short, temperature-controlled, flexible hose to the respiration gas meter for measurement of the minute volume. Canisters of silica gel were introduced into the gas stream intermittently to trap the expired water vapor, thus providing a gravimetric cross-check of the calculated respiratory water loss. Figure 6 shows the location of the silica gel canister in the expiration system. The canisters were employed intermittently because their use interfered slightly with the minute volume measurement. When they were not in use, they were replaced by a length of stainless-steel piping, which permitted more accurate measurements of minute volume.

Minute volume measurement. The respiratory minute volume was determined by passing the expired gas through a respiration gas meter (model 59, Max-Planck Institute for Work Physiology). This instrument was developed for determining the minute volume of humans performing various work loads, and it was ideally suited for this test program. The meter was encased in a pressuretight cylindrical housing with a Plexiglas window permitting a constant visual readout. Total pressure and drybulb temperature of the gas meter were monitored and accounted for in all quantitative measurements. The respiration gas meter was calibrated frequently to assure an accurate and precise volumetric measurement. From the respiration meter housing, the expired gas was returned to the plenum chamber and exhausted into the altitude chamber. Figure 6 shows the location of the respiration gas meter.

Suspension of the mouthpiece. The bifurcated mouthpiece was fitted with a rubber athletic-type mouthpiece, which was inserted into the subject's mouth. Because of the weight of the apparatus, the entire assembly was suspended by attaching two cords to the ΔP transducers, which were situated at the center of gravity of the mouthpiece assembly. The cords were run through a series of pulleys attached overhead in the altitude chamber and secured to a suspension spring. The suspension spring, located near the top of the chamber, ran parellel to the floor and was anchored to a perforated plate by a wire hook so that it could be moved to any position along that plate, thus lowering or raising the mouthpiece and enabling it to be set at a comfortable elevation for each individual. The suspension spring allowed the mouthpiece assembly to move up and down with the subject's normal amplitude of vertical and horizontal oscillation during exercise on the treadmill. The strategic location and critical balancing of the suspension system allowed an extended tolerance by the individual for wearing the mouthpiece, and there were no complaints from any of the subjects.

FIGURE 5

Subject in test position.

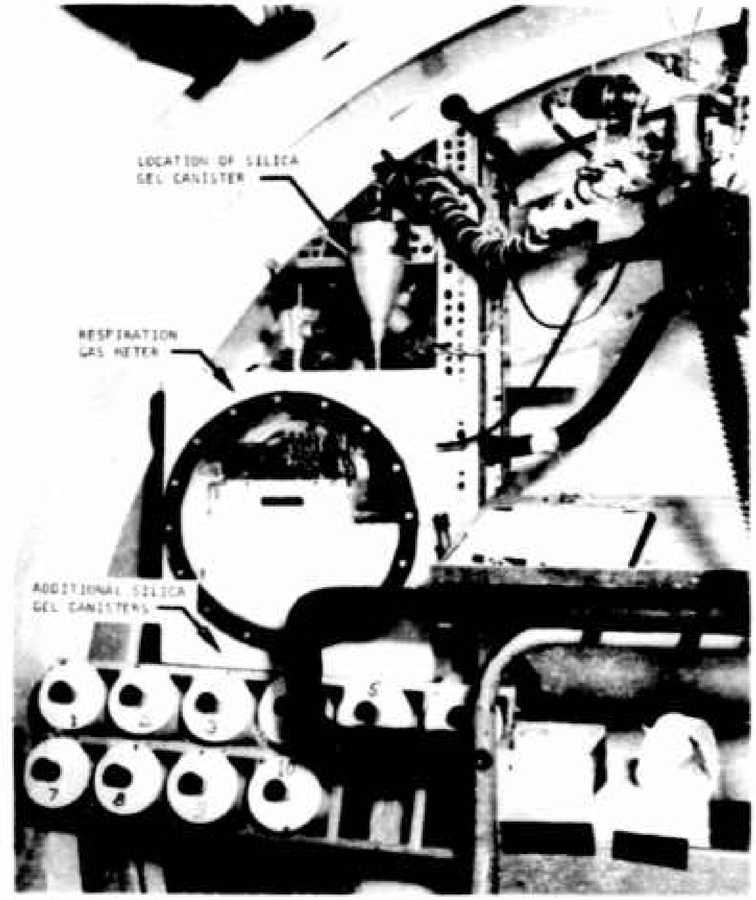


FIGURE 6

Respiration meter.

Bioinstrumentation

Skin temperature. The temperature of the skin was measured with copper-constantan thermocouples applied firmly with tape at the following locations (fig. 7):

1. Dorsum of foot.
2. Anteromedial aspect of leg between knee and ankle.
3. Medial aspect of thigh, midway between perineum and knee.
4. Back, over supraspinatus muscle.
5. Chest, 1 in. medial to nipple.
6. Anterolateral aspect of upper arm, midway between shoulder and elbow.
7. Posterior aspect of forearm, midway between elbow and wrist.
8. Dorsum of hand.
9. Forehead.

A 24-channel Brown-Honeywell recorder was used to record skin temperatures.

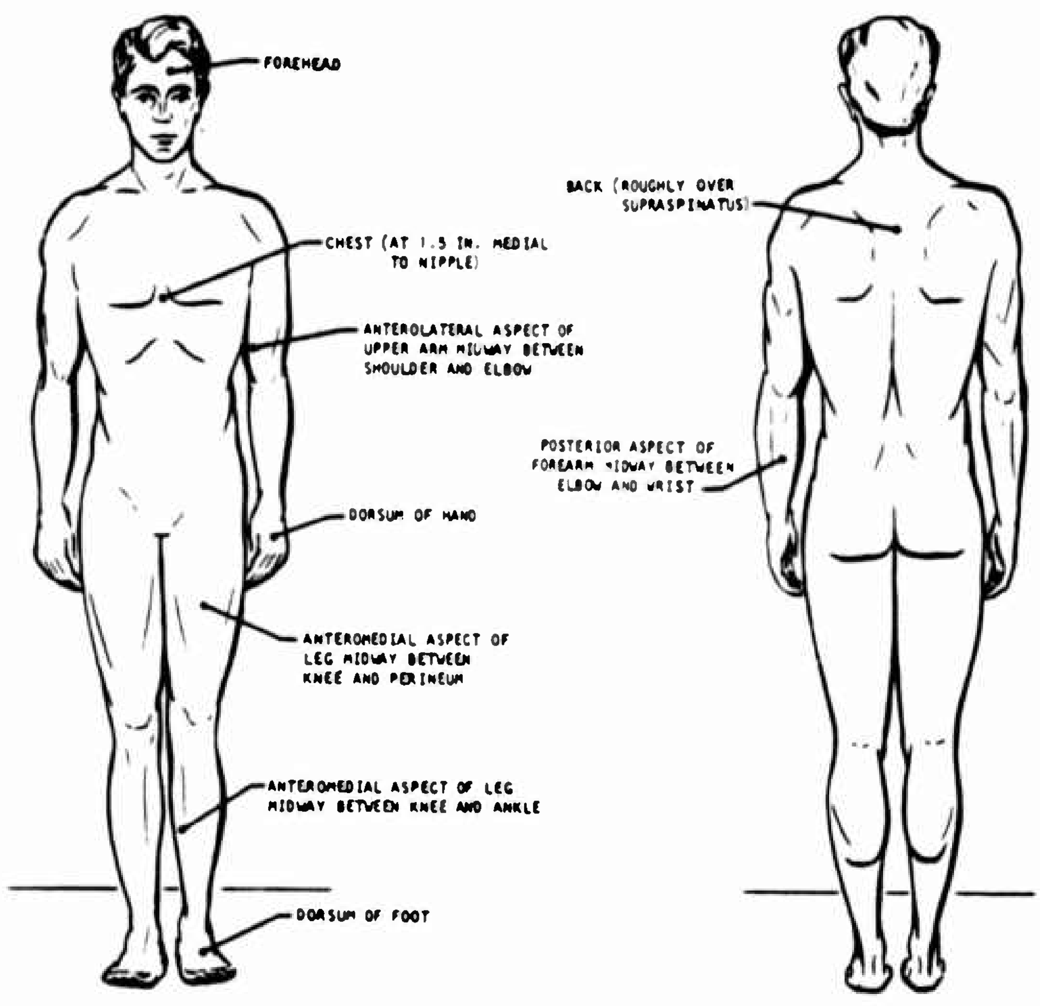


FIGURE 7

Skin temperature sensor locations.

Tympanic temperature. Changes in temperature of the eardrum were measured with a specially designed copper-constantan thermocouple (22) that was placed in the ear so that the thermoelectric junction of the wires was touching the tympanic membrane. The reference junction for the tympanic thermocouple was immersed in a thermos jar filled with ice.

Rectal temperature. Temperature changes in the rectum were measured with a thermistor probe (0.46 cm. in diameter and 3.9 cm. long) that was inserted approximately 10 cm. beyond the anal sphincter. Recordings of temperature both from the rectum and tympanic membrane were made on an Offner Type S Dynograph.

All temperatures were recorded automatically and continuously at sea level, at simulated altitudes of 19,000 and 34,000 ft., and in some instances during simulated ascent and descent.

Electrocardiograph. Continuous electrocardiograms were taken using a three-electrode system consisting of a bipolar modified V_4 lead and a ground. Recording and monitoring were done on the Dynograph; at 5-minute intervals, the speed of the recording paper was increased from 1 mm./sec. to 10 mm./sec. to facilitate examination of the tracing.

Respiration. Respiratory rate was determined with a Beckman respiration strain gage, attached to a belt strapped around the thorax, and by short-time-constant thermistors located in the inspiratory and expiratory chambers of the bifurcated mouthpiece. Monitoring and recording of respiratory rate were done on the Dynograph.

Respiratory minute volume was determined by measuring the flow of expired air through a respiration gas meter (model 59, Max Planck Institute for Work Physiology).

Test protocol

After the attachment of all sensors, the subject was seated in the altitude chamber. A nose clamp was applied, and the subject commenced to breathe oxygen through the mouthpiece apparatus. The oxygen was brought to the desired experimental condition, and the subject continued to breathe for a stabilizing period of 15 to 30 minutes. At this time, the subject stood and began walking on the treadmill at a rate of 2 m.p.h.; this continued for a 30-minute period, and constituted the first test mode. Then the subject, still breathing on the apparatus, was seated and remained seated for 30 minutes; this period constituted the second test mode. The third test mode followed immediately and was identical to the first, except that the treadmill was set at 4 m.p.h. After this condition, the subject was allowed to rest and to breathe through an oxygen mask while the chamber was evacuated to 7 p.s.i.; this rest period was 30 minutes long. The next three test modes were conducted at 7 p.s.i. and were identical to the first three; they were followed by another 30-minute rest period as the chamber pressure was evacuated to 3.5 p.s.i. Three test modes then were conducted at 3.5 p.s.i.; these were identical to the tests conducted at sea level and at 7 p.s.i. At the conclusion of these modes, the test was terminated, the chamber returned to ambient pressure, and the subject removed from the chamber. A typical daily test schedule is shown in figure 8. Data were collected for all the dependent and independent parameters throughout each test mode at 5-minute intervals. All data were reduced; however, to ensure that the subject was at physiologic equilibrium and thus to utilize the most meaningful data, only the last 5 minutes of each test mode were utilized for analysis of the effects of the independent variables.

The data were recorded on oscillographs, as digital printouts on recorder devices, and by hand on data sheets. Data requiring computation were recorded during the tests on data sheets arranged for IBM keypunch operations.

Instrumentation error analysis

Respiratory water loss, grams per minute. The generalized equation from which respiratory water loss, in grams per minute, was computed is represented by the expression:

$$W_{H_2O} = K_1 \frac{Q}{t} \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right]$$

where W_{H_2O} = water loss in grams per minute; Q = ventilatory gas volume in liters; t = time; P_2H_2O and P_1H_2O = partial pressure of water in expiratory and inspiratory gas, respectively; and T_2 and T_1 = absolute temperature of the expiratory and inspiratory gas, respectively. The parameters measured,

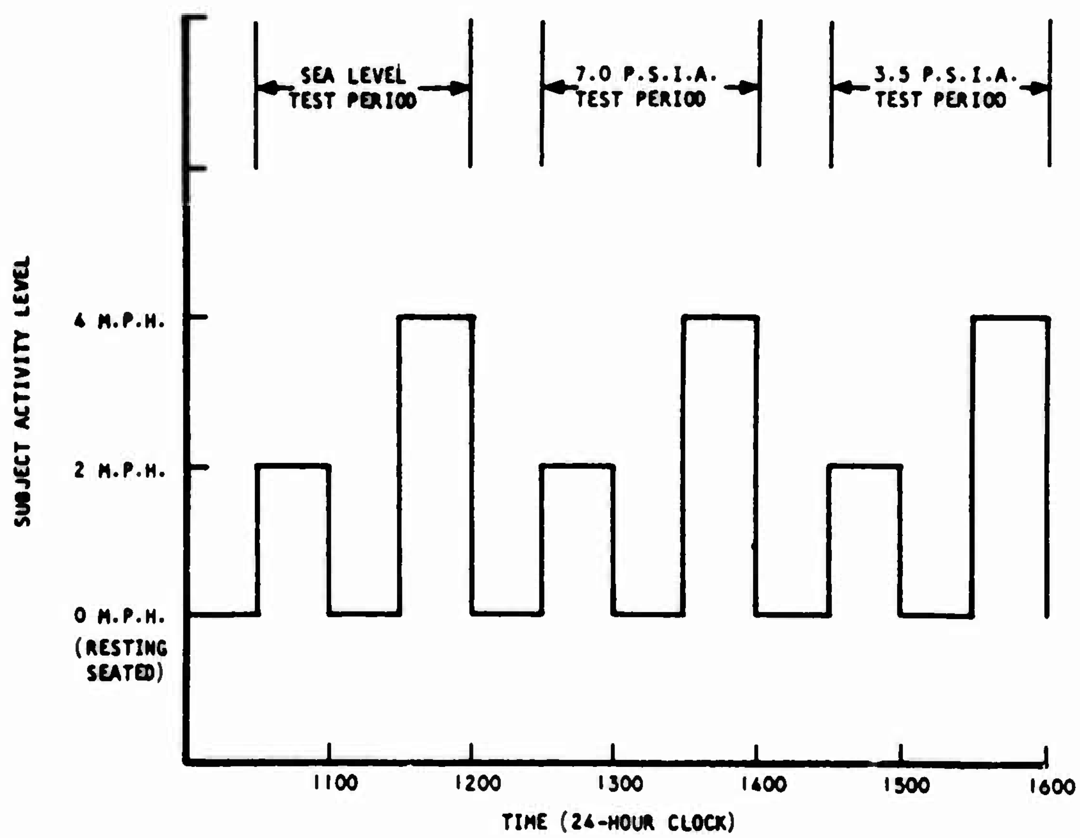


FIGURE 8

Typical daily test schedule.

the instruments used in measurement, and the percent error applicable to the range or value of each parameter are listed below:

Parameter	*Instrument*	*Error*	*Comments*
Ventilatory gas volume	Max Planck respiration gas meter	±3.5% at rest ±2.3% at 4 m.p.h.	Includes RSS meter error of ±2%
Partial pressure of water	AiResearch-designed dewpoint indicator	±1%	
Absolute temp. of gas	Electronic multichannel strip recorder	±0.14%	
Timed interval	Electric clock	±1.7% (includes reaction time)	

Where a = the error in ventilatory gas volume; b = the error in the timing intervals; c = the error in the partial pressure of water, and d = the error in absolute temperature, the total error was computed from:

$$W_{H_2O} = K_1 \frac{Q \pm Qa}{t \pm tb} \left[K_2 \frac{P_2H_2O \pm P_2H_2O_c}{T_2 \pm T_2d} - K_3 \frac{P_1H_2O \pm P_1H_2O_c}{T_1 \pm T_1d} \right]$$

$$= K_1 \frac{Q}{t} \left(\frac{1 \pm a}{1 \pm b}\right) \left[K_2 \frac{P_2H_20}{T_2} \left(\frac{1 \pm c}{1 \pm d}\right) - K_3 \frac{P_1H_20}{T_1} \left(\frac{1 \pm c}{1 \pm d}\right) \right]$$

$$= K_1 \frac{Q}{t} \left(\frac{1 \pm a}{1 \pm b}\right) \left(\frac{1 \pm c}{1 \pm d}\right) \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right]$$

$$E_{W_{H_2O}} = K_1 \frac{Q}{t} \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right] -$$

$$K_1 \frac{Q}{t} \left(\frac{1 \pm a}{1 \pm b}\right) \left(\frac{1 \pm c}{1 \pm d}\right) \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right]$$

$$= K_1 \frac{Q}{t} \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right] \left[1 - \left(\frac{1 \pm a}{1 \pm b}\right) \left(\frac{1 \pm c}{1 \pm d}\right) \right]$$

And, after eliminating terms contributing less than 0.1% error,

$$E_{W_{H_2O}} = K_1 \frac{Q}{t} \left[K_2 \frac{P_2H_2O}{T_2} - K_3 \frac{P_1H_2O}{T_1} \right] \left[\pm a \pm b \pm c \pm d \right]$$

The maximum errors at the indicated mode are:

Percent error	*Mode*
± 6.34	Rest
± 5.14	4 m.p.h.

As indicated above, the most critical source of error was the respiration gas meter. The device used for calibration of volume-measuring equipment was a simple variable-rate, variable-volume piston pump. Rate was selected by a

Zero Max Motor assembly, and stroke volume was determined by positioning the connecting rod at precision-drilled holes on the driving plate. Dead-space volume between the piston and the cylinder head was eliminated by adjusting the cylinder barrel flush against the piston at the top center. A schematic of the variable-volume piston pump is shown in figure 9. Piston-to-cylinder sealing was effected by a Teflon piston ring assembly designed by Haskell Seals, Glendale, Calif. Haskell claims negligible leakage at pressures up to 1,000 p.s.i.

Seven precision-drilled holes were provided on the driving plate with piston displacements of 1,500 through 4,500 cm.³

Dimensions for the pump were:

Cylinder area		334.012 cm.²
Linkage length from piston to driving plate		70.0 cm.²
Radii of precision holes giving a stroke of	1,500 cm.³	2.246 cm.
	2,000 cm.³	2.994 cm.
	2,500 cm.³	3.743 cm.
	3,000 cm.³	4.491 cm.
	3,500 cm.³	5.139 cm.
	4,000 cm.³	5.988 cm.
	4,500 cm.³	6.736 cm.

Displaced volume errors arising from measurment errors are:

Measurement	*Error*	*Percent error in expected volume*
Cylinder diameter	13×10^{-3} cm. (0.005 in.)	± 0.13
Piston stroke	26×10^{-3} cm. (0.010 in.)	± 0.57 at 1,500 cm.³
		± 0.19 at 4,500 cm.³

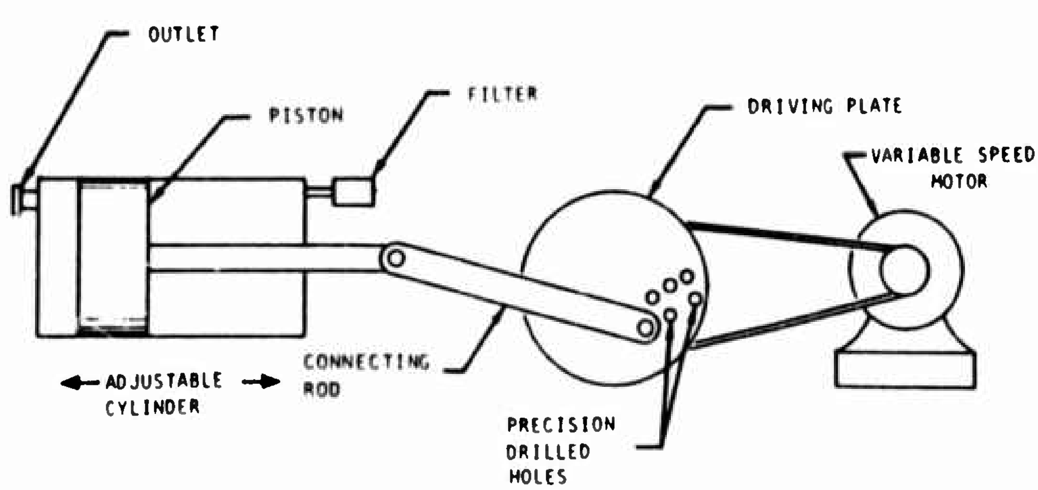


FIGURE 9

Variable-volume piston pump.

Thermal expansion errors resulting from a temperature change of 50° F. are indicated below:

Expansion of	*Percent error and direction*
Piston linkage	0.57 at 1,500 cm.^{3}; decrease
Cylinder barrel	0.10 increase

Coupling together the piston pump and a Godart spirometer produced the following data:

Indicated stroke (cm.^{3})	*Strokes per min.*	*Spirometer reading (cm.^{3})*
1,500	5	1,470 to 1,475
2,000	5	2,005 to 2,010
2,500	5	2,495 to 2,500
3,000	5	3,015 to 3,020
3,500	5	3,515 to 3,520

Calibrating the piston pump by water displacement at the 1,500-cm.^{3} and 2,000-cm.^{3} positions indicated stroke volume 1% less than expected.

From the physical, spirometer, and water displacement data, it is concluded that the accuracy of the piston pump is $\pm 1\%$ under all conditions.

The variability and ruggedness of the pump permitted calibration of the test circuits under actual operating conditions—i.e., hose lengths, valving, and expected rate and depth of respiration.

For this experiment, the respiration gas meter was calibrated against the piston pump at the 1,500-cm.^{3} and 2,000-cm.^{3} stroke positions and at simulated respiration rates of 5 to 10, 10 to 15, and 15 to 20 per minute.

Shown below are representative data from these tests:

Stroke vol. (liters)	*Strokes per min.*	*Pump volume delivered*	*Gas meter reading*	*Percent error rel. to pump*	
2	5-10	60	59.5	0.8	Cylinder set for 4,000 cm.^{3}
2	5-10	210	208.4	0.8	
2	5-10	60	60.0	0.0	Cylinder set for 2,000 cm.^{3}
2	10-15	60	60.1	0.2	
2	15-20	60	59.6	0.7	
1.5	5-10	45	44.5	1.1	Cylinder set for 4,000 cm.^{3}
1.5	10-15	45	44.8	0.4	
1.5	15-20	45	50.6	0.8	
1.5	15-20	45	44.5	1.1	Cylinder set for 2,000 cm.^{3}

Before this experiment, the piston pump had been used in a slightly different capacity to draw a known quantity of gas through the respiration gas meter. Downstream from a large gas storage bottle were inserted, respectively, the gas meter and the piston pump. Appropriate valving and a demand regulator at the storage bottle permitted measurable quantities of gas to be drawn through the meter. The schematic shown in figure 9 clarifies the test circuit.

After correcting for temperature and pressure, the following data were reduced:

Stroke vol. (liters)	*Strokes per min.*	*Wt. of gas delivered (kg.)*	*Vol. ATPD (liters)*	*Meter read (liters)*	*Percent error*
1.5	15	10.551	805	808	0.37
1.5	15	11.608	888	887	0.12
1.5	5.5	2.566	585	578	1.2

Thus, at the start of this experiment the respiration meter was accurate to within ±1% with respect to the piston pump. At the conclusion of this experiment (total volume measured by the meter approximately 253,000 liters), the accuracy of the respiration meter again was checked with the piston pump and was found to be ±2.4% with the pump set at a 1.5-liter stroke at 20 to 25 strokes per minute.

Computational procedures

General. The raw data were collected during this experiment at intervals of 5 minutes. Sufficient personnel and recording equipment were employed so that all of the data could be recorded for a single point in time. The data were recorded directly from the instruments on data sheets prepared for IBM keypunch operations and were subsequently keypunched and entered, along with a preprogram, in an IBM 7074 computer. At all points of listing, the consistency of times, test conditions, subjects, and dates were compared for accurate listings and computations. The results obtained and presented in this report have been cross-checked with all pertinent control points to assure proper comparative data. The computer presented all data required for presentation or subsequent analysis, whether or not these data were required directly for the computations.

The primary parameters which required computation from the raw data were (1) respiratory water loss, in grams per minute; (2) minute volume, in liters per minute; and (3) mean skin temperature, in degrees Fahrenheit. The other dependent variables were either directly recorded as raw data or were computational byproducts of the primary computations discussed below.

Respiratory water loss, grams per minute. Respiratory water loss rate was determined from the inspired and expired dewpoint temperatures and minute volume. The basic equation used was the general state equation of ideal gases:

$$PV = WRT, \text{ or } W = \frac{PV}{RT}$$

where W = rate of water loss; P = partial pressure of water vapor; V = minute volume (rate); R = gas constant for water vapor; and T = absolute temperature.

In this particular program, the rate of water loss was computed in grams per minute. The necessary constants and conversion factors required to adjust the raw data to a consistent and operable form were included in the computer program. The water loss rate was computed by using the difference between the outlet and inlet vapor conditions and the minute volume. The data collected on the data sheets which were required to determine water loss rates were:

Data sheet	*Parameter*	*Remarks*
1	Outlet dewpoint	Converted to partial pressure
1	Inlet dewpoint	Converted to partial pressure
2	Meter temperature	Converted to absolute temperature
2	Expired volume (meter summation)	For calculation of minute volume
4	Meter pressure	

These data may be reduced to:

W = K (expired vapor pressure − inspired vapor pressure) (minute volume)

where K is a combined correction constant permitting the computation of water loss, W, in units of grams per minute.

Minute volume, liters per minute. The minute volume was determined from the metered expired air, as described previously, and the time lapse. The data used from the data sheets to determine minute volume were:

Data sheet	*Parameter*	*Remarks*
2	Volume meter	Summation of expired volume in liters
(All)	Time	Time lapse from previous volume reading to current reading

These data reduce to: minute volume (in liters per minute) is equal to the difference between the present and the previous meter readings (in liters) divided by the elapsed time (in minutes).

The inspired minute volume was not calculated and was assumed to be the same as expired minute volume.

Mean skin temperature, °F. The mean skin temperature was determined by the average temperature of nine skin temperature measurements taken from the selected locations as described previously. The data used from the data sheets were:

Data sheet	*Parameter*	*Remarks*
3	Skin temperature	Points 1 – 4
4	Skin temperature	Points 5 – 9

These reduce to:

$$\text{Skin temperature average} = \frac{\Sigma T_N}{N}$$

The average skin temperature was obtained from all measurements listed; i.e., if only seven temperatures were listed, N would equal 7. This factor did not prove to be a problem since all nine temperatures were listed.

III. SUBJECTS

Five adult males were utilized as subjects in this experiment. Detailed history and complete physical examination of each subject revealed no abnormalities. Each subject was tested under every experimental condition. The sequence of test conditions was randomized for the independent variables of inhaled dewpoint and drybulb temperature. A systematic sequence, however, existed for the variables work rate and pressure, as described previously in section II.

No subject was tested more frequently than twice a week, and a minimum period of three days elapsed between successive tests with the same subject.

The subjects are described in table I, which give a summary of relevant subject characteristics.

TABLE I

Summary of relevant subject characteristics

	Subjects				
	J. W.	K. C.	W. S.	D. E.	R. G.
Height, cm.	175.26	176.53	177.80	184.15	187.96
Weight, kg.	64.12	78.96	75.16	62.56	91.16
Body surface area, m.^{2}	1.79	1.94	1.92	1.82	2.16
Vital capacity (VC), cc.	4,494	5,756	5,479	5,284	5,633
Tidal volume, cc.	462	677	769	1,239	923
Rate, breaths/min.	16	14	12	7	10
Inspiratory reserve volume, cc.	2,124	3,293	2,524	1,754	2,247
Expiratory reserve volume, cc.	1,908	1,785	2,155	2,278	2,462
Functional residual capacity, cc.	3,648	3,859	4,219	4,436	4,486
Residual volume (RV), cc.	1,740	2,075	2,065	2,159	1,921
Total lung capacity (TCL), cc.	6,234	7,830	7,544	7,443	7,553
Forced expiratory volume (FEV), 1.0 sec., cc.	3,539	4,094	3,909	4,679	4,709
$\frac{RV}{TLC} \times 100$, percent	27.9	26.5	27.4	29.0	25.4
$\frac{FEV}{VC} \times 100$, percent	78.7	75.0	71.3	88.5	83.6

All subjects seated; BTPS, sea level.

Lung volume and ventilation measurements were made on the subjects with a Godart Pulmonet (No. 59004). Residual volume and functional residual capacity were determined by the closed-circuit method with helium used as the test gas. These measurements, summarized in table I, were made to permit comparison of data between the individual subjects tested, and comparison with published data for similar subjects. The values obtained are within normal limits for healthy male subjects in the same age range (23-26).

IV. RESULTS

General

The results of the experiment are presented in the following pages in graphs. Correlations, analysis of variance summary tables, tabulations of means, and standard deviations for all dependent variables will be found in the original report.[1] In general, the presentation of the results is organized about the matrices of independent variables, and the results are grouped by dependent variables. Consequently, reference should be made to the analysis of variance matrices for a given independent variable when detailed orientation or interpretation is desired.

The correlations presented in this section are correlations for groups of all rows, columns, or slices of these matrices. The correlations are presented only for cases of significant independent variables and only when $r \geq .5$. Correlations are also given for each dependent variable and respiratory water loss (grams per minute and grams per liter) for cases where $r \geq .5$.

The analysis of variance matrices are presented to illustrate the method in which the data were organized for treatment by this statistical technic. Individual matrices are presented for each condition of inhaled drybulb or inhaled dewpoint temperature. The significance of the remaining independent variables on the dependent variable under consideration is presented along the axes of rows, columns, and slices of each matrix.

Analysis of variance summary tables are presented for each matrix. The independent variables associated with rows, columns, and slices of the matrix are defined by R, C, and S, respectively.

The means, standard deviations, and number of subjects for each cell of the matrix follow each summary table and are identified by the matrix and the following conventions:

1. Three-dimensional analysis of variance

Inhaled drybulb temperature constant

Row 1	14.7 p.s.i.
Row 2	7.0 p.s.i.
Row 3	3.5 p.s.i.
Column 1	40° F. inhaled dewpoint temperature
Column 2	60° F. inhaled dewpoint temperature
Column 3	80° F. inhaled dewpoint temperature
Slice 1	0 m.p.h.
Slice 2	2 m.p.h.
Slice 3	4 m.p.h.

[1] AiResearch Manufacturing Co. report LS-140 prepared under contract No. AF 41(609)-2389.

Inhaled dewpoint temperature constant

Row 1	14.7 p.s.i.
Row 2	7.0 p.s.i.
Row 3	3.5 p.s.i.
Column 1	55° F. inhaled drybulb temperature
Column 2	75° F. inhaled drybulb temperature
Column 3	95° F. inhaled drybulb temperature
Slice 1	0 m.p.h.
Slice 2	2 m.p.h.
Slice 3	4 m.p.h.

2. Two-dimensional analysis of variance

Inhaled drybulb temperature 55° F. at 40° F. inhaled dewpoint temperature

Row 1	14.7 p.s.i.
Row 2	7.0 p.s.i.
Row 3	3.5 p.s.i.
Column 1	0 m.p.h.
Column 2	2 m.p.h.
Column 3	4 m.p.h.

Inhaled dewpoint temperature 80° F. at 95° F. inhaled drybulb temperature

Row 1	14.7 p.s.i.
Row 2	7.0 p.s.i.
Row 3	3.5 p.s.i.
Column 1	0 m.p.h.
Column 2	2 m.p.h.
Column 3	4 m.p.h.

The graphs were selected for clarity of presentation, and their axes are not consistent throughout this section. The dependent variables are plotted by use of the means of the measurements taken for all five subjects.

Respiratory water loss, grams per minute

This de er lent variable represents the increment of water added to the gas during r on as a function of time. It will be noted that each independent variable k rate, pressure, inhaled dewpoint temperature, and inhaled dry-bulb tem ure) has a significant effect on respiratory water loss. The means of the relevant data are presented graphically in figures 10, 11, and 12. The analysis of variance matrices for this dependent variable are given in figure 13.

In general, the rate of water addition during respiration increases more than 100% as work rate increases from rest to 4 m.p.h. on the treadmill. The rates of water loss observed ranged from 0.060 gm./min. to 0.548 gm./min. Raising the inhaled dewpoint temperature results in a decrease in the rate of water loss. An increase in either pressure or inhaled drybulb temperature results in an increased rate of water loss.

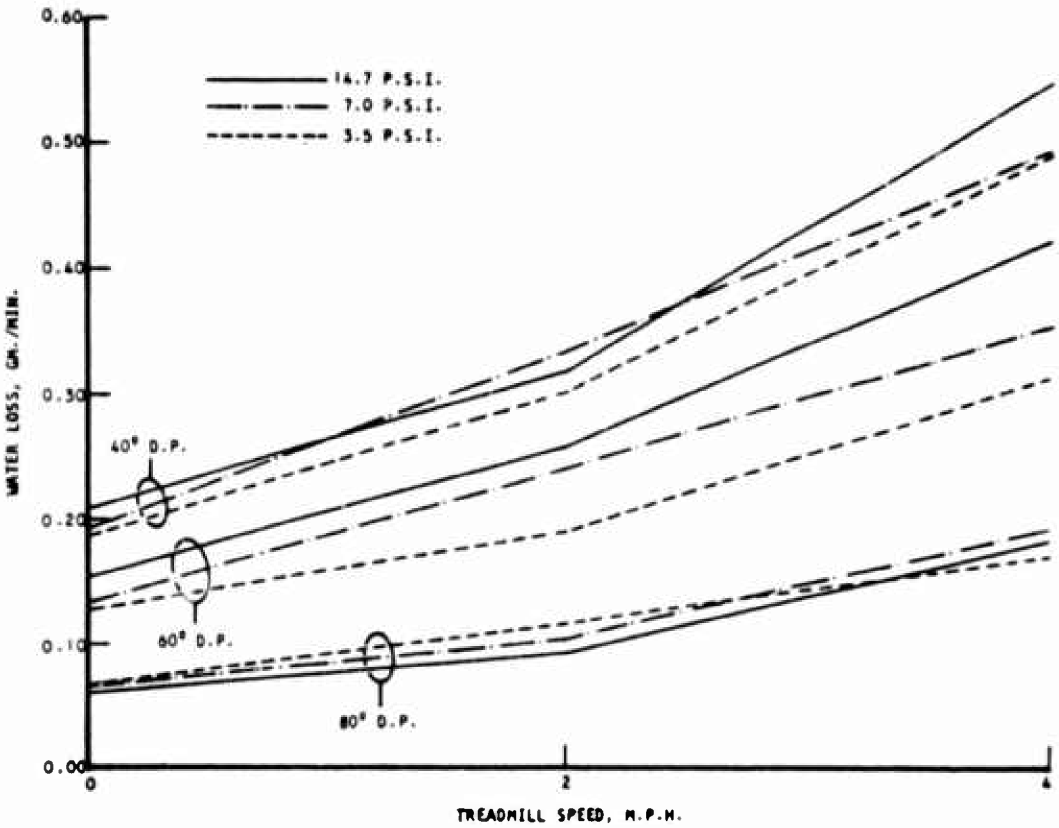


FIGURE 10

Respiratory water loss, grams per minute, as a function of treadmill speed, miles per hour, at 95° F. drybulb.

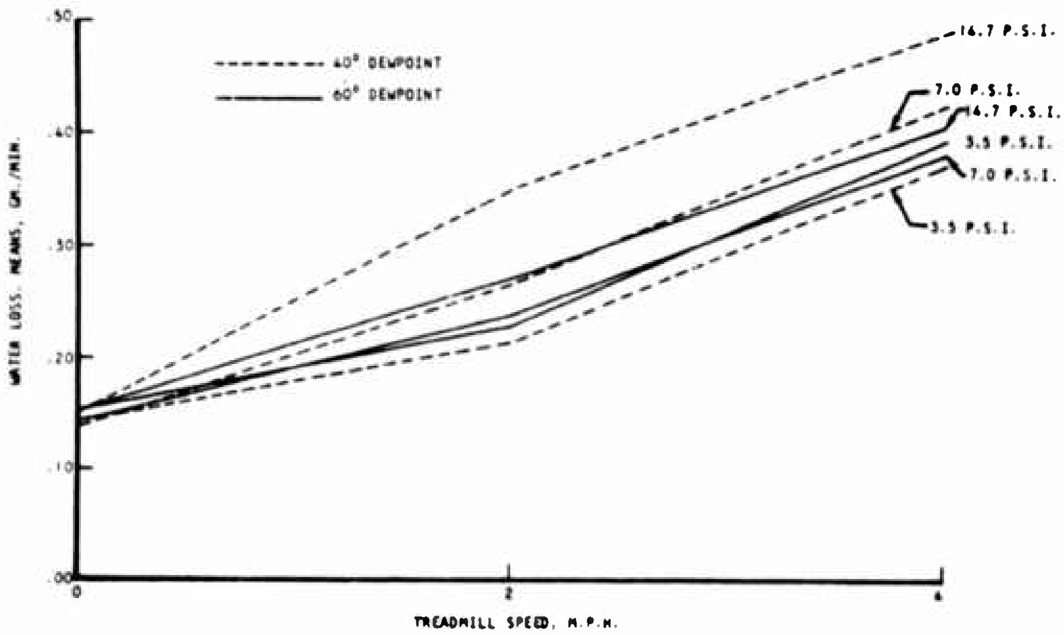


FIGURE 11

Respiratory water loss, grams per minute, as a function of treadmill speed, miles per hour, at 75° F. drybulb.

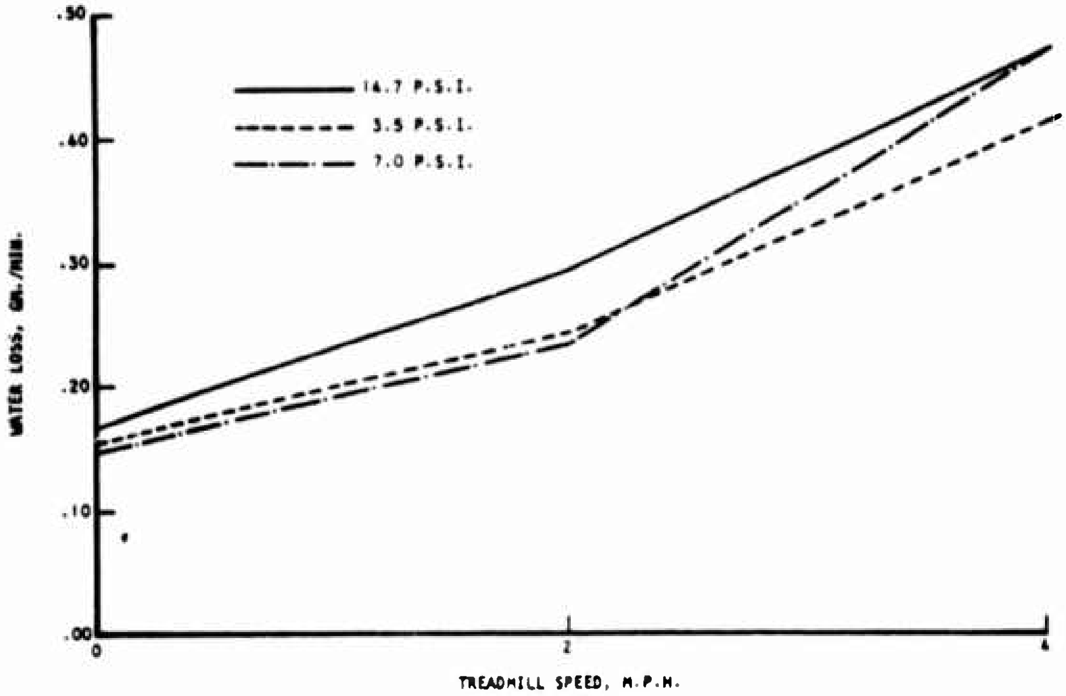


FIGURE 12

Respiratory water loss, grams per minute, as a function of treadmill speed, miles per hour, at 55° F. drybulb.

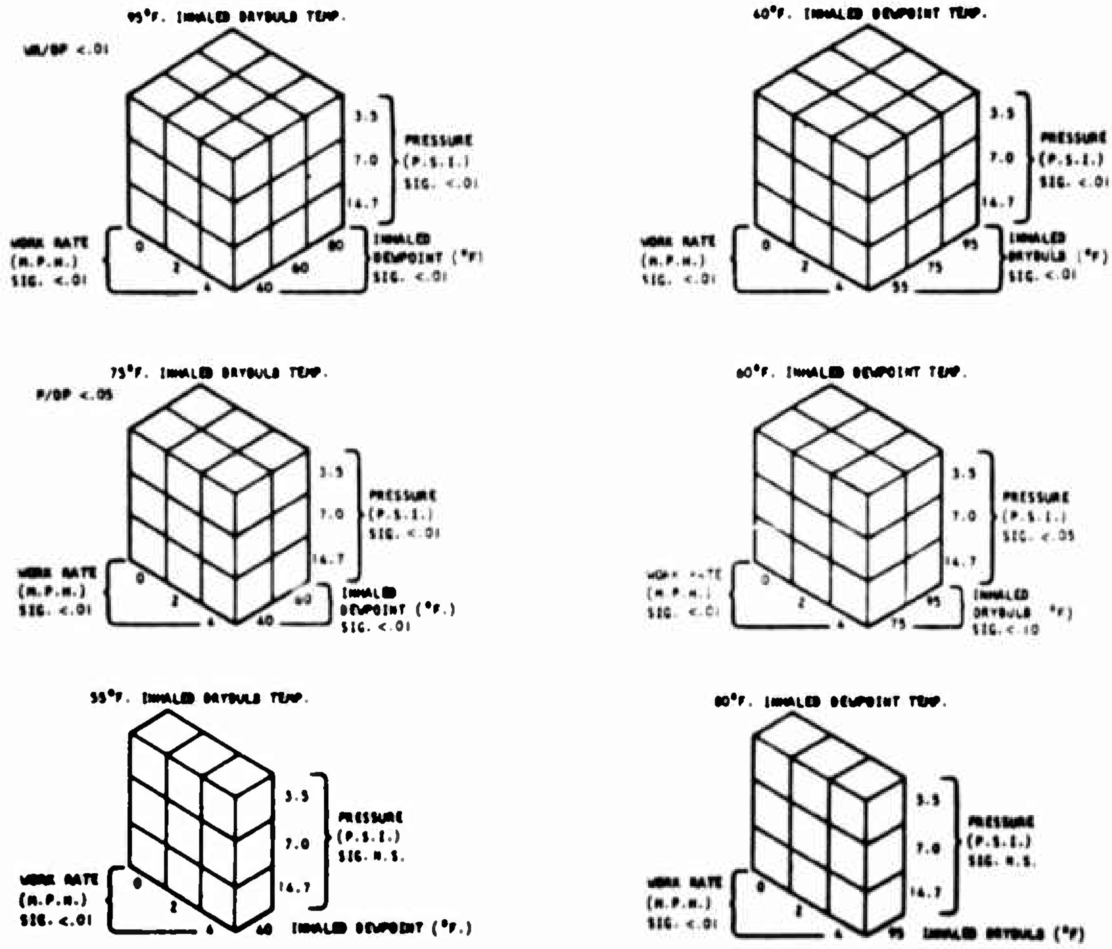


FIGURE 13

Analysis of variance matrices; dependent variable water loss, grams per minute.

The linearity of the data is evidenced by the table of correlations (table II). Many of the correlations of interest were not computed because of the magnitude of the task.

The IBM 7074 data printouts showing the analysis of variance summary tables and the cell and general means are presented as figures 14 through 19.

Respiratory water loss, grams per liter

This dependent variable represents the increment of water added to each liter of respired gas for a given test condition. The means of the relevant data are presented graphically in figures 20, 21, and 22. The analysis of variance matrices for respiratory water loss, grams per liter, are given in figure 23. The amount of water added to the respired gas was observed to vary from 0.0067 gm./liter to 0.0268 gm./liter. This measurement of the rate of water loss differs from the previous dependent variable, respiratory loss measured in grams per minute, by eliminating the effect of work rate and the related effects of minute volume and respiratory rate. The decrease in respiratory water loss caused by increasing inhaled dewpoint is again quite apparent. The effects of pressure and inhaled drybulb temperature on this parameter are not clearly defined. The high correlations (.98 and .92) indicated in table III, however, show the predictability of water loss per respired liter when inhaled dewpoint temperature is known. The IBM 7074 data printouts showing the analysis of variance summary tables and the cell and general means are presented as figures 24 through 29.

Because of the rather small numbers, the data were transformed by 10^3. This transformation still exists in the tabulation of means and standard deviations. In reading grams per liter means and standard deviations, therefore, the correlation 10^{-3} should be applied.

Total expired water rate, grams per minute

The means of the relevant data for this dependent variable are presented graphically in figures 30 through 33.

TABLE II

Respiratory water loss, grams per minute

With independent variables		r
Work rate, m.p.h., at	95° F. drybulb	.66250
	75° F. drybulb	.95069
	55° F. drybulb	.96807
	40° F. dewpoint	.94523
	60° F. dewpoint	.96025
	80° F. dewpoint	.97292
Dewpoint temp., °F., at	95° F. drybulb	.68265

Correlations, as computed, with significant independent variables, when r ≥ .5.

THREE DIMENSIONAL ANALYSIS OF VARIANCE

DELTA WATER RATE GM/MIN 95° F DRYBULB

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	1.09015	0.54508
B DEWPOINT	2	1.06589	0.53295
C PRESSURE	2	0.03524	0.01762
AB	4	0.14183	0.03546
AC	4	0.01503	0.00376
BC	4	0.00569	0.00142
ABC	8	0.00351	0.00044
W CELLS	102	0.23655	0.00232
TOTAL	128	2.59390	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.20800	0.15400	0.06000
	SIGMA	0.03271	0.02302	0.00000
	NO SUBJECTS	5	5	4
ROW 2	MEAN	0.19200	0.13400	0.06500
	SIGMA	0.03564	0.00548	0.02380
	NO SUBJECTS	5	5	4
ROW 3	MEAN	0.18800	0.12800	0.06800
	SIGMA	0.04550	0.03033	0.01643
	NO SUBJECTS	5	5	5

SLICE 2

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.32000	0.25800	0.09250
	SIGMA	0.05385	0.03962	0.01258
	NO SUBJECTS	5	5	4
ROW 2	MEAN	0.33600	0.24200	0.10500
	SIGMA	0.04219	0.03271	0.03000
	NO SUBJECTS	5	5	4
ROW 3	MEAN	0.30400	0.19200	0.11800
	SIGMA	0.05550	0.03564	0.03564
	NO SUBJECTS	5	5	5

SLICE 3

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.54800	0.42200	0.18250
	SIGMA	0.07259	0.06870	0.03304
	NO SUBJECTS	5	5	4
ROW 2	MEAN	0.49600	0.35400	0.19000
	SIGMA	0.06189	0.06768	0.03830
	NO SUBJECTS	5	5	4
ROW 3	MEAN	0.49200	0.31400	0.17000
	SIGMA	0.10035	0.08503	0.03464
	NO SUBJECTS	5	5	5

GENERAL MEAN= 0.23

FIGURE 14

Respiratory water loss, grams per minute, 95° F. drybulb.

THREE DIMENSIONAL ANALYSIS OF VARIANCE

DELTA WATER RATE GM/MIN 75°F DRYBULB

SUMMARY TABLE

SOURCE	DF	SS	MS
A (WORK RATE)	2	1.05375	0.52687
B (DEWPOINT)	1	0.00900	0.00900
C (PRESSURE)	2	0.04524	0.02262
AB	2	0.00765	0.00382
AC	4	0.01893	0.00473
BC	2	0.01811	0.00905
ABC	4	0.00697	0.00174
W CELLS	72	0.19852	0.00276
TOTAL	89	1.35816	

SLICE 1

		COL 1	COL 2
ROW 1	MEAN	0.15000	0.15200
	SIGMA	0.05099	0.03271
	NO SUBJECTS	5	5
ROW 2	MEAN	0.13800	0.14200
	SIGMA	0.03347	0.03962
	NO SUBJECTS	5	5
ROW 3	MEAN	0.14000	0.15200
	SIGMA	0.03391	0.01924
	NO SUBJECTS	5	5

SLICE 2

		COL 1	COL 2
ROW 1	MEAN	0.35000	0.27000
	SIGMA	0.06245	0.04123
	NO SUBJECTS	5	5
ROW 2	MEAN	0.26600	0.23800
	SIGMA	0.04393	0.04712
	NO SUBJECTS	5	5
ROW 3	MEAN	0.21400	0.22800
	SIGMA	0.03647	0.04604
	NO SUBJECTS	5	5

SLICE 3

		COL 1	COL 2
ROW 1	MEAN	0.48800	0.40600
	SIGMA	0.09680	0.06148
	NO SUBJECTS	5	5
ROW 2	MEAN	0.42400	0.38000
	SIGMA	0.08050	0.07550
	NO SUBJECTS	5	5
ROW 3	MEAN	0.37000	0.39200
	SIGMA	0.05148	0.02387
	NO SUBJECTS	5	5

GENERAL MEAN= 0.27

FIGURE 15

Respiratory water loss, grams per minute, 75° F. drybulb.

As might be expected, the total expired water rate in grams per minute responds to the independent variables in much the same way as respiratory water loss expressed in grams per minute. This relationship is reflected in the unusually high coefficients of correlation shown in the lower portion of table IV. The effect of dewpoint for the 75° F. inhaled drybulb condition also reflects the effect observed for rate of water loss (grams per minute); however, the effect of inhaled dewpoint on total expired water is not clear for other drybulb conditions.

Total expired water rate, grams per liter

The means of this dependent variable, total expired water rate in grams per liter, are presented graphically in figures 34, 35, and 36.

The total expired water rate expressed in grams per liter, in contrast to total expired water rate in grams per minute, differs considerably from the respiratory water loss. Increases in inhaled dewpoint temperature correspond to increased total expired water, although the water loss decreases. Once again, however, inhaled dewpoint temperature is the main effective independent variable, and high correlations are observed between inhaled dewpoint and total expired water, grams per liter (table V).

RESPIRATORY WATER LOSS (ORAL)-DELTA WATER RATE GM/MIN 55 DEG. F DRYBULB

B=PRESSURE C=WORKRATE S=40 DEG. F DEG. DEWPOINT

SUMMARY TABLE

SOURCE	DF	SS	MS
A	0	0.00000	0.00000
B WORK RATE	2	0.64689	0.32344
C PRESSURE	2	0.01212	0.00606
AB	0	0.00000	0.00000
AC	0	0.00000	0.00000
BC	4	0.00993	0.00248
ABC	0	0.00000	0.00000
W CELLS	35	0.16732	0.00478
TOTAL	43	0.83625	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.16800	0.29400	0.47000
	SIGMA	0.02280	0.05899	0.07071
	NO SUBJECTS	5	5	5
ROW 2	MEAN	0.14750	0.23600	0.47000
	SIGMA	0.05188	0.08081	0.11203
	NO SUBJECTS	4	5	5
ROW 3	MEAN	0.15600	0.24400	0.41200
	SIGMA	0.03847	0.03647	0.09445
	NO SUBJECTS	5	5	5

GENERAL MEAN= 0.29

FIGURE 16

Respiratory water loss, grams per minute, 55° F. drybulb.

THREE DIMENSIONAL ANALYSIS OF VARIANCE

DELTA WATER RATE GM/MIN 40°F DEWPOINT

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	1.99628	0.99814
B DRYBULB	2	0.09024	0.04512
C PRESSURE	2	0.05812	0.02906
AB	4	0.01888	0.00472
AC	4	0.01784	0.00446
BC	4	0.01232	0.00308
ABC	8	0.01842	0.00230
W CELLS	107	0.42000	0.00393
TOTAL	133	2.63208	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.16800	0.15000	0.20800
	SIGMA	0.02280	0.05099	0.03271
	NO SUBJECTS	5	5	5
ROW 2	MEAN	0.14750	0.13800	0.19200
	SIGMA	0.05188	0.03347	0.03564
	NO SUBJECTS	4	5	5
ROW 3	MEAN	0.15600	0.14000	0.18800
	SIGMA	0.03847	0.03391	0.04550
	NO SUBJECTS	5	5	5

SLICE 2

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.29400	0.35000	0.32000
	SIGMA	0.05899	0.06245	0.05385
	NO SUBJECTS	5	5	5
ROW 2	MEAN	0.23600	0.26600	0.33600
	SIGMA	0.08081	0.04393	0.04219
	NO SUBJECTS	5	5	5
ROW 3	MEAN	0.24400	0.23400	0.30400
	SIGMA	0.03647	0.05128	0.05550
	NO SUBJECTS	5	5	5

SLICE 3

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.47000	0.48800	0.54800
	SIGMA	0.07071	0.09680	0.07259
	NO SUBJECTS	5	5	5
ROW 2	MEAN	0.47000	0.42400	0.49600
	SIGMA	0.11203	0.08050	0.06189
	NO SUBJECTS	5	5	5
ROW 3	MEAN	0.41200	0.37000	0.49200
	SIGMA	0.09445	0.05148	0.10035
	NO SUBJECTS	5	5	5

GENERAL MEAN= 0.31

FIGURE 17

Respiratory water loss, grams per minute, 40° F. dewpoint.

THREE DIMENSIONAL ANALYSIS OF VARIANCE

DELTA WATER RATE GM/MIN 60°F DEWPOINT

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	0.83411	0.41705
B DRYBULB	1	0.00729	0.00729
C PRESSURE	2	0.02838	0.01419
AB	2	0.00153	0.00076
AC	4	0.00800	0.00200
BC	2	0.00936	0.00468
ABC	4	0.00461	0.00115
W CELLS	72	0.16408	0.00228
TOTAL	89	1.05737	

SLICE 1

		COL 1	COL 2
ROW 1	MEAN	0.15200	0.15400
	SIGMA	0.03271	0.02302
	NO SUBJECTS	5	5
ROW 2	MEAN	0.14200	0.13400
	SIGMA	0.03962	0.00548
	NO SUBJECTS	5	5
ROW 3	MEAN	0.15200	0.12800
	SIGMA	0.01924	0.03033
	NO SUBJECTS	5	5

SLICE 2

		COL 1	COL 2
ROW 1	MEAN	0.27000	0.25800
	SIGMA	0.04123	0.03962
	NO SUBJECTS	5	5
ROW 2	MEAN	0.23800	0.24200
	SIGMA	0.04712	0.03271
	NO SUBJECTS	5	5
ROW 3	MEAN	0.22800	0.19200
	SIGMA	0.04604	0.03564
	NO SUBJECTS	5	5

SLICE 3

		COL 1	COL 2
ROW 1	MEAN	0.40600	0.42200
	SIGMA	0.06148	0.06870
	NO SUBJECTS	5	5
ROW 2	MEAN	0.38000	0.35400
	SIGMA	0.07550	0.06768
	NO SUBJECTS	5	5
ROW 3	MEAN	0.39200	0.31400
	SIGMA	0.02387	0.08503
	NO SUBJECTS	5	5

GENERAL MEAN= 0.25

FIGURE 18

Respiratory water loss, grams per minute, 60° F. dewpoint.

Minute volume, liters per minute (ATP)

As expected, the data on this dependent variable show that minute volume increases markedly with increases in work rate. Also, minute volume is shown to be directly related to pressure, increasing as pressure increases (figs. 37, 38, and 39). The differences in minute volume due to pressure effects, though not large at the lower work rates (1.0 liter/min. or less), are quite large at the higher work rates (up to 8 liters/min. for a difference of approximately 33%). This pressure effect is consistent and statistically significant.

The linearity of minute volume as a function of work rate for each condition of inhaled dewpoint and drybulb temperature is indicated by the high correlations shown in table VI. The table also contains correlations between minute volume and water loss in grams per liter. These correlations indicate that, for a given set of inhaled conditions, the rate of water loss can be closely predicted by knowledge of minute volume.

RESPIRATORY WATER LOSS(ORAL)-DELTA WATER RATE GM/MIN 80 DEG. F DEWPOINT
B=PRESSURE C=WORKRATE

SUMMARY TABLE

SOURCE	DF	SS	MS
A	0	0.00000	0.00000
B WORK RATE	2	0.08880	0.04440
C PRESSURE	2	0.00049	0.00025
AB	0	0.00000	0.00000
AC	0	0.00000	0.00000
BC	4	0.00203	0.00051
ABC	0	0.00000	0.00000
W CELLS	30	0.02351	0.00078
TOTAL	38	0.11483	

RESPIRATORY WATER LOSS(ORAL)-DELTA WATER RATE GM/MIN 80 DEG. F DEWPOINT
B=PRESSURE C=WORKRATE

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	0.06000	0.09250	0.18250
	SIGMA	0.00000	0.01258	0.03304
	NO SUBJECTS	4	4	4
ROW 2	MEAN	0.06500	0.10500	0.19000
	SIGMA	0.02380	0.03000	0.03830
	NO SUBJECTS	4	4	4
ROW 3	MEAN	0.06800	0.11800	0.17000
	SIGMA	0.01643	0.03564	0.03464
	NO SUBJECTS	5	5	5

GENERAL MEAN= 0.12

FIGURE 19

Respiratory water loss, grams per minute, 80° F. dewpoint.

The data indicate that inhaled dewpoint had an effect on minute volume which is statistically significant for both the 75° F. and 95° F. inhaled drybulb temperature conditions. The reason for the apparent effect of dewpoint on minute volume, which is opposite for these two conditions, is unknown.

Expired dewpoint temperature, °F.

The expired dewpoint temperature depends primarily on the inspired dewpoint temperature. The following graphs and the statistical analyses (figs. 40, 41, and 42 and table VII) indicate that expired dewpoint temperature is elevated significantly as the inspired dewpoint temperature is raised.

A systematic and significant effect of inhaled drybulb temperature is apparent when the inhaled dewpoint temperature is 40° F. Under this condition, expired dewpoint increases as a direct function of inspired drybulb temperature. Pressure also has an apparent effect on expired dewpoint for the 80° F. inhaled dewpoint, 95° F. inhaled drybulb, temperature condition.

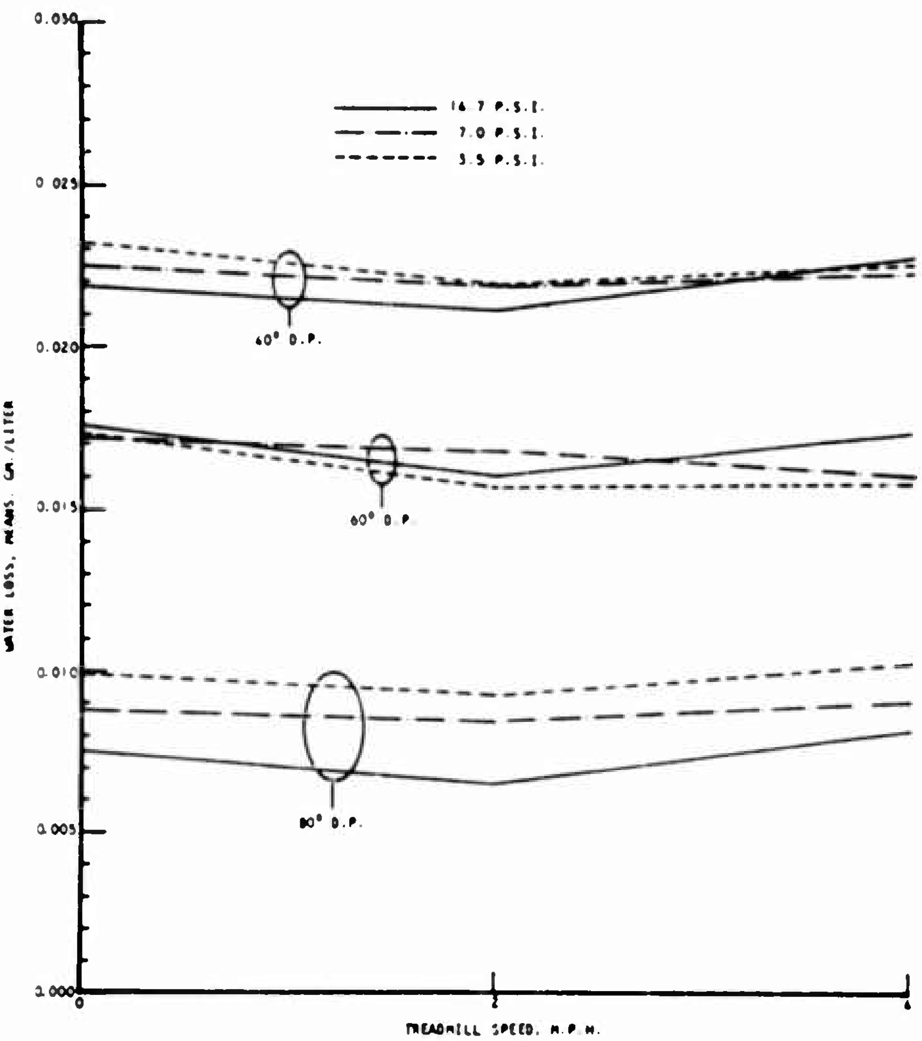


FIGURE 20

Respiratory water loss, grams per liter, as a function of treadmill speed, miles per hour, at 95° F. drybulb.

Expired drybulb temperature, °F.

Expired drybulb temperature varies directly with inhaled drybulb temperature and inhaled dewpoint temperature, and varies inversely with work rates; these effects may be seen in figures 43, 44, and 45. These relationships are consistent and statistically significant. Highest correlations with expired drybulb temperature, however, are obtained with inhaled drybulb temperatures, as shown in table VIII.

Respiration rate, breaths per minute

Respiration rate, as might be expected, varies considerably for a given subject, between subjects, and across conditions. Work rate, however, exerts a direct, consistent, and statistically significant effect on respiration rate. The means of the relevant data for respiration rate are presented graphically in figures 46, 47, and 48.

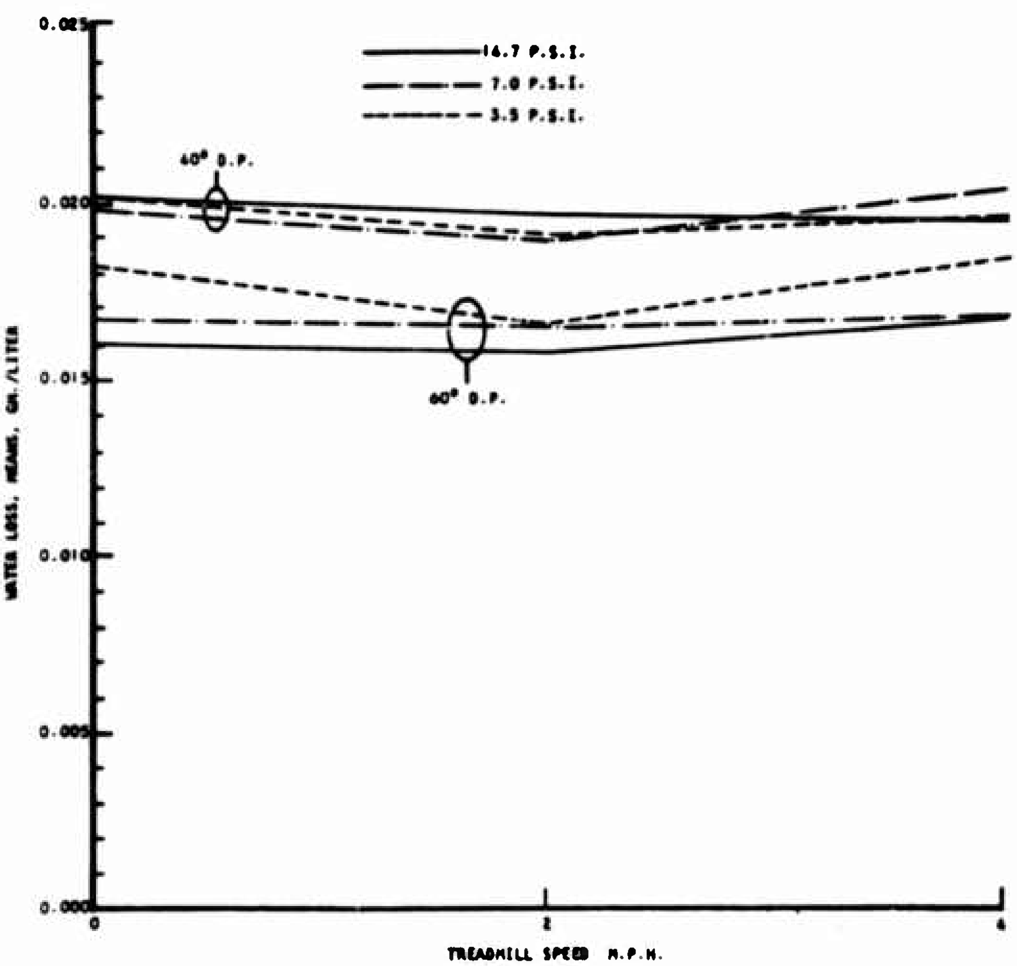


FIGURE 21

Respiratory water loss, grams per liter, as a function of treadmill speed, miles per hour, at 75° F. drybulb.

Heart rate, beats per minute

As expected, heart rate varies directly with work rate and inversely with pressure (figs. 49, 50, and 51). This relationship is consistent and statistically significant.

Mean skin temperature, °F.

Average skin temperature shows considerable variance among both subjects and conditions, as illustrated in figures 52, 53, and 54. There are, however, two significant parameters: work rate and pressure. Skin temperature increases with decreasing pressure, apparently because of lower rates of heat transfer. On the other hand, skin temperature decreases with increasing work load because of perspiration.

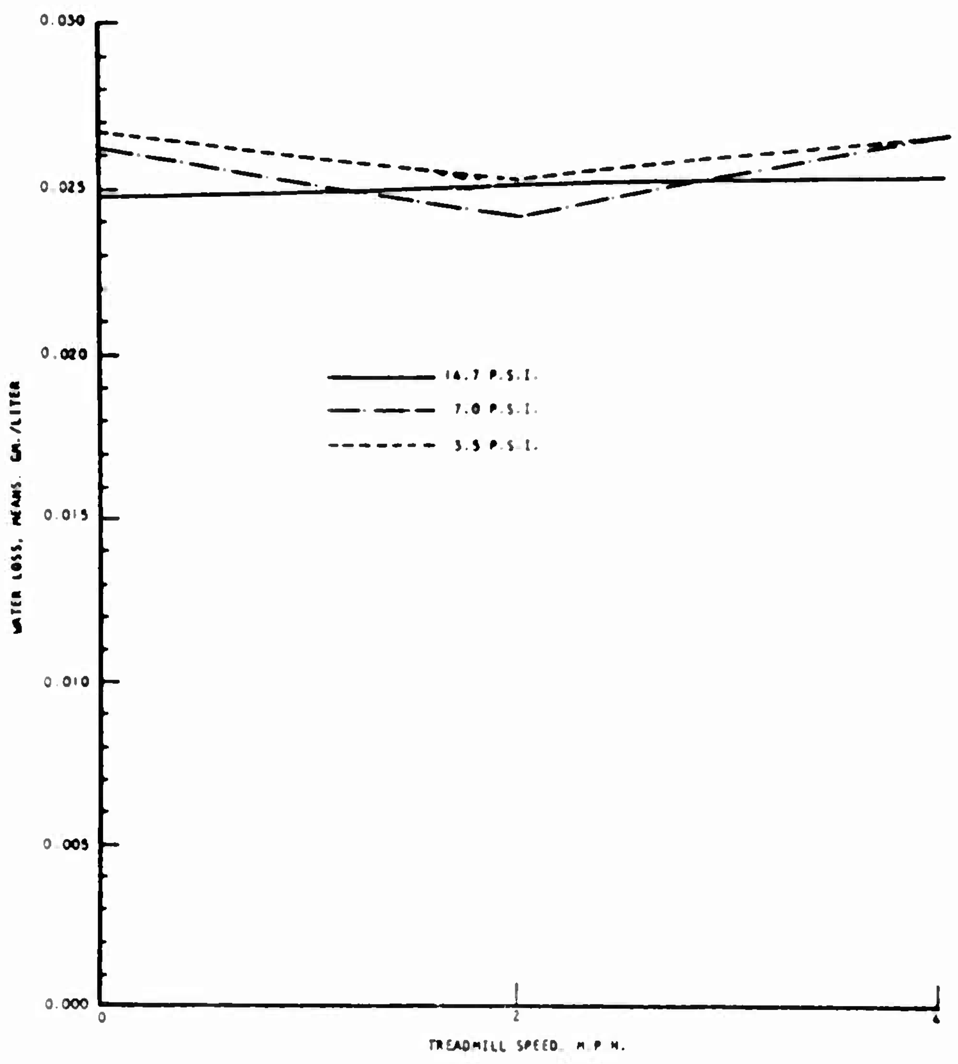


FIGURE 22

Respiratory water loss, grams per liter, as a function of treadmill speed, miles per hour, at 55° F. drybulb.

Rectal temperature, °F

The dependent variable rectal temperature, as anticipated, varies directly with work rate. Rectal temperature was also observed to vary with the parameters that affect heat transfer from the lungs. In particular, rectal temperature increases as both inhaled drybulb and inhaled dewpoint temperatures increase (fig. 55 through 58). It will be recalled that increases in inhaled dewpoint correspond to decreases in respiratory water loss (i.e., latent heat loss).

Rectal temperature also varies inversely with pressure. It is not known, however, whether this effect is due to the lower sensible heat loss at reduced pressures, an artifact of the daily test sequence, a combination of the two, or other factors associated with pressure. It will be recalled, however, that decreases in pressure correspond to lower rates of respiratory water loss and lower minute volume. These two effects in turn correspond to lowered respiratory heat transfer, which may be reflected in elevated core temperatures as a function of pressure.

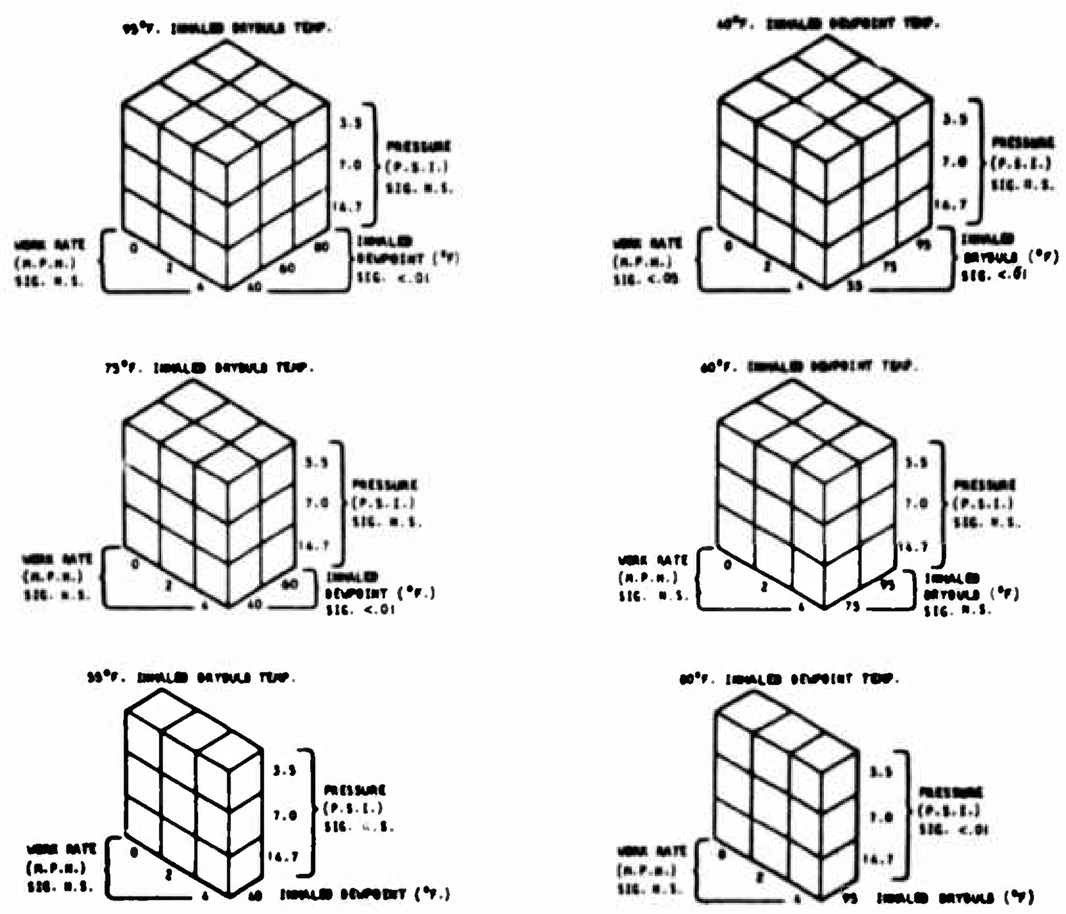


FIGURE 23

Analysis of variance matrices; dependent variable respiratory water loss, grams per liter.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE GM/L 95 DEG. F

A=PRESSURE C=DEWPOINT S=WORKRATE DATA TRANS 1000

SUMMARY TABLE

SOURCE		DF	SS	MS
A	WORK RATE	2	19.47900	9.73950
B	DEWPOINT	2	3836.24100	1918.12050
C	PRESSURE	2	2.89800	1.44900
AB		4	6.82800	1.70700
AC		4	8.80000	2.20000
BC		4	43.44000	10.86000
ABC		8	2.14200	0.26775
W CELLS		102	724.13200	7.09933
TOTAL		128	4643.96000	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	21.92000	17.54000	7.50000
	SIGMA	3.52379	4.14524	0.36515
	NO SUBJECTS	5	5	4
ROW 2	MEAN	22.50000	17.20000	8.80000
	SIGMA	2.02114	3.32190	2.55473
	NO SUBJECTS	5	5	4
ROW 3	MEAN	23.18000	17.34000	9.86000
	SIGMA	2.06688	6.18167	1.52905
	NO SUBJECTS	5	5	5

SLICE 2

		COL 1	COL 2	COL 3
ROW 1	MEAN	21.14000	16.18000	6.55000
	SIGMA	1.69352	2.40354	1.63605
	NO SUBJECTS	5	5	4
ROW 2	MEAN	21.88000	16.82000	8.45000
	SIGMA	1.98293	2.97785	0.96782
	NO SUBJECTS	5	5	4
ROW 3	MEAN	21.92000	15.70000	9.32000
	SIGMA	1.53036	3.18983	1.92666
	NO SUBJECTS	5	5	5

SLICE 3

		COL 1	COL 2	COL 3
ROW 1	MEAN	22.86000	17.44000	8.12500
	SIGMA	2.34153	2.11140	0.97425
	NO SUBJECTS	5	5	4
ROW 2	MEAN	22.38000	16.14000	9.02500
	SIGMA	1.97914	2.72635	1.17580
	NO SUBJECTS	5	5	4
ROW 3	MEAN	22.66000	15.88000	10.28000
	SIGMA	1.82291	3.61483	2.69574
	NO SUBJECTS	5	5	5

GENERAL MEAN= 15.87

FIGURE 24

Respiratory water loss, grams per liter, at 95° F. drybulb.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE GM/L 75 DEG. F

R=PRESSURE C=DEWPOINT S=WORKRATE   DATA TRANS 1000

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	11.70600	5.85300
B DEWPOINT	1	186.62500	186.62500
C PRESSURE	2	2.95300	1.47650
AB	2	1.28700	0.64350
AC	4	2.66200	0.66550
BC	2	5.05200	2.52600
ABC	4	5.83600	1.45900
W CELLS	72	254.87600	3.53994
TOTAL	89	470.99700	

SLICE 1

		COL 1	COL 2
ROW 1	MEAN	20.20000	16.80000
	SIGMA	0.30822	1.96850
	NO SUBJECTS	5	5
ROW 2	MEAN	19.78000	16.76000
	SIGMA	1.73118	1.58597
	NO SUBJECTS	5	5
ROW 3	MEAN	20.16000	17.22000
	SIGMA	1.07610	4.09536
	NO SUBJECTS	5	5

SLICE 2

		COL 1	COL 2
ROW 1	MEAN	19.64000	15.72000
	SIGMA	1.13270	1.69322
	NO SUBJECTS	5	5
ROW 2	MEAN	18.88000	16.46000
	SIGMA	1.40961	1.83929
	NO SUBJECTS	5	5
ROW 3	MEAN	19.08000	16.52000
	SIGMA	1.95115	1.74557
	NO SUBJECTS	5	5

SLICE 3

		COL 1	COL 2
ROW 1	MEAN	19.40000	16.56000
	SIGMA	2.04695	1.47919
	NO SUBJECTS	5	5
ROW 2	MEAN	20.30000	16.72000
	SIGMA	1.57162	1.84986
	NO SUBJECTS	5	5
ROW 3	MEAN	19.56000	18.32000
	SIGMA	1.41527	2.37634
	NO SUBJECTS	5	5

GENERAL MEAN= 18.23

FIGURE 25

Respiratory water loss, grams per liter, at 75° F. drybulb.

TABLE III

Respiratory water loss, grams per liter

With independent variables		r
Dewpoint temp., °F., at	95° F. drybulb	.98414
	75° F. drybulb	.92814
Drybulb temp., °F., at	40° F. dewpoint	.54439
Pressure, p.s.i.a., at	80° F. dewpoint	.89872

Correlations, as computed, with significant independent variables, when r ≥ .5.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE GM/L 55 DEG. F DRYBULB

B=PRESSURE C=WORKRATE DATA TRANS 1000

SUMMARY TABLE

SOURCE	DF	SS	MS
A	0	0.00000	0.00000
B WORK RATE	2	7.64400	3.82200
C PRESSURE	2	2.83700	1.41850
AB	0	0.00000	0.00000
AC	0	0.00000	0.00000
BC	4	4.25200	1.06300
ABC	0	0.00000	0.00000
W CELLS	36	172.39600	4.78878
TOTAL	44	187.12900	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	21.92000	21.14000	22.86000
	SIGMA	3.52378	1.69352	2.34158
	NO SUBJECTS	5	5	5
ROW 2	MEAN	22.50000	22.08000	22.38000
	SIGMA	2.02114	2.09571	1.97914
	NO SUBJECTS	5	5	5
ROW 3	MEAN	23.18000	21.92000	22.66000
	SIGMA	2.06688	1.53036	1.82291
	NO SUBJECTS	5	5	5

GENERAL MEAN= 22.29

FIGURE 26

Respiratory water loss, grams per liter, at 55° F. drybulb.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE GM/L 40 DEG. F DEWPOINT

R=PRESSURE C=DRYBULB S=WORKRATE DATA TRANS 1C00

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	36.13600	18.06800
B DRYBULB	2	220.18700	110.09350
C PRESSURE	2	4.06700	2.03350
AB	4	4.87700	1.21925
AC	4	12.84800	3.21200
BC	4	4.24400	1.06100
ABC	8	18.65800	2.33225
W CELLS	107	378.17200	3.53432
TOTAL	133	679.18900	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	18.66CC0	20.20000	21.90000
	SIGMA	1.19499	0.30822	3.48927
	NO SUBJECTS	5	5	5
ROW 2	MEAN	19.90000	19.78000	22.50000
	SIGMA	2.C51C2	1.73118	2.02114
	NO SUBJECTS	4	5	5
ROW 3	MEAN	21.20000	20.16000	23.18000
	SIGMA	2.90172	1.07610	2.06688
	NO SUBJECTS	5	5	5

SLICE 2

		COL 1	COL 2	COL 3
ROW 1	MEAN	19.10000	19.64000	21.14000
	SIGMA	1.65982	1.13270	1.69352
	NO SUBJECTS	5	5	5
ROW 2	MEAN	18.40000	18.88000	21.88000
	SIGMA	1.21861	1.40961	1.98293
	NO SUBJECTS	5	5	5
ROW 3	MEAN	17.64000	19.08000	22.26000
	SIGMA	2.33731	1.95115	1.54693
	NO SUBJECTS	5	5	5

SLICE 3

		COL 1	COL 2	COL 3
ROW 1	MEAN	19.16000	19.40000	22.06000
	SIGMA	1.40107	[illegible]4695	2.49058
	NO SUBJECTS	5	5	5
ROW 2	MEAN	2C.86C00	2C.30C00	22.38000
	SIGMA	1.90997	1.57162	1.97914
	NO SUBJECTS	5	5	5
ROW 3	MEAN	2C.28000	19.56C00	22.66CC0
	SIGMA	1.89658	1.41527	1.82291
	NO SUBJECTS	5	5	5

GENERAL MEAN= 20.45

FIGURE 27

Respiratory water loss, grams per liter, at 40° F. dewpoint.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE GM/L 60 DEG. F DEWPOINT

R=PRESSURE C=DRYBULB S=WORKRATE DATA TRANS 1000

SUMMARY TABLE

SOURCE	DF	SS	MS
A WORK RATE	2	12.90200	6.45100
B DRYBULB	1	0.19700	0.19700
C PRESSURE	2	0.37300	0.18650
AB	2	5.02700	2.51350
AC	4	5.31000	1.32750
BC	2	11.66400	5.83200
ABC	4	5.19600	1.29900
W CELLS	72	637.40800	8.85289
TOTAL	89	678.07700	

SLICE 1

		COL 1	COL 2
ROW 1	MEAN	16.80000	17.54000
	SIGMA	1.96850	4.14524
	NO SUBJECTS	5	5
ROW 2	MEAN	16.76000	17.20000
	SIGMA	1.58997	3.32190
	NO SUBJECTS	5	5
ROW 3	MEAN	17.22000	17.34000
	SIGMA	4.09536	6.18167
	NO SUBJECTS	5	5

SLICE 2

		COL 1	COL 2
ROW 1	MEAN	15.72000	16.18000
	SIGMA	1.69322	2.40354
	NO SUBJECTS	5	5
ROW 2	MEAN	16.46000	16.82000
	SIGMA	1.83529	2.87785
	NO SAMPLES	5	5
ROW 3	MEAN	16.52000	15.70000
	SIGMA	1.74557	3.18983
	NO SUBJECTS	5	5

SLICE 3

		COL 1	COL 2
ROW 1	MEAN	16.56000	17.44000
	SIGMA	1.47919	2.11140
	NO SUBJECTS	5	5
ROW 2	MEAN	16.72000	16.14000
	SIGMA	1.84986	2.72635
	NO SUBJECTS	5	5
ROW 3	MEAN	18.32000	15.98000
	SIGMA	2.37634	3.61483
	NO SUBJECTS	5	5

GENERAL MEAN= 16.74

FIGURE 28

Respiratory water loss, grams per liter, at 60° F. dewpoint.

RESPIRATORY WATER LOSS (ORAL) DELTA WATER RATE .GM/L 80 DEG. F DEWPOINT

R=PRESSURE C=WORKRATE DATA TRANS 1000

SUMMARY TABLE

SOURCE		DF	SS	MS
:		0	0.00000	0.00000
E	WORK RATE	2	6.99280	3.49640
:	PRESSURE	2	39.52970	19.76485
AB		0	0.00000	0.00000
AC		0	0.00000	0.00000
BC		4	1.03600	0.25900
ABC		0	0.00000	0.00000
W CELLS		30	91.15900	3.03863
TOTAL		38	138.71750	

SLICE 1

		COL 1	COL 2	COL 3
ROW 1	MEAN	7.50000	6.55000	8.12500
	SIGMA	0.36515	1.63605	0.97425
	NO SUBJECTS	4	4	4
ROW 2	MEAN	8.80000	8.45000	9.02500
	SIGMA	2.55473	0.96782	1.17580
	NO SUBJECTS	4	4	4
ROW 3	MEAN	9.88000	9.32000	10.28000
	SIGMA	1.53525	1.92666	2.69574
	NO SUBJECTS	5	5	5

GENERAL MEAN= 8.66

FIGURE 29

Respiratory water loss, grams per liter, at 80° F. dewpoint.

TABLE IV

Total expired water rate, grams per minute

With independent variables		r
Work rate, m.p.h., at	95° F. drybulb	.96596
	75° F. drybulb	.93039
	55° F. drybulb	.96966
	40° F. dewpoint	.94597
	60° F. dewpoint	.96289
	80° F. dewpoint	.97326
With respiratory water loss, gm./min.		
95° F. drybulb,	80° F. dewpoint	.93310
95° F. drybulb,	60° F. dewpoint	.97962
95° F. drybulb,	40° F. dewpoint	.98841
75° F. drybulb,	60° F. dewpoint	.98830
75° F. drybulb,	40° F. dewpoint	.99912
55° F. drybulb,	40° F. dewpoint	.99754

Correlations, as computed, with significant independent variables, and with respiratory water loss, grams per minute, when r ≥ .5.

TABLE V

Total expired water, grams per liter

		r
With independent variables		
Dewpoint temp., °F., at	95° F. drybulb	.83275
	75° F. drybulb	.92960
Drybulb temp., °F., at	40° F. dewpoint	.76240
Pressure, p.s.i.a., at	80° F. dewpoint	.87931
With respiratory water loss, gm./min.		None ≥ .5
With respiratory water loss, gm./liter		
95° F. drybulb,	80° F. dewpoint	.75048
95° F. drybulb,	60° F. dewpoint	.85741
95° F. drybulb,	40° F. dewpoint	.67981
75° F. drybulb,	60° F. dewpoint	.90059
75° F. drybulb,	40° F. dewpoint	.94048
[illegible]5° F. drybulb,	40° F. dewpoint	.95627

Correlations, as computed, with significant independent variables, and with respiratory water loss, grams per minute and grams per liter, when r ≥ .5.

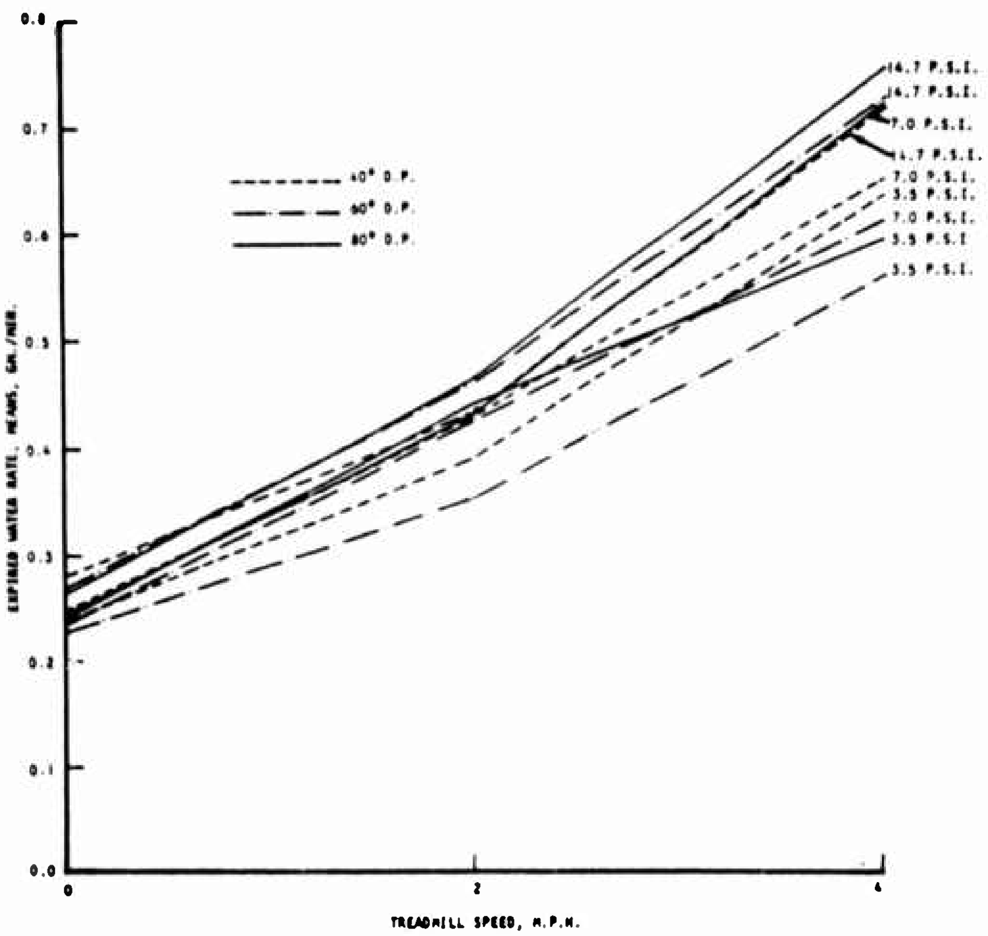


FIGURE 30

Total expired water rate, grams per minute, as a function of treadmill speed, miles per hour, at 95° F. drybulb.

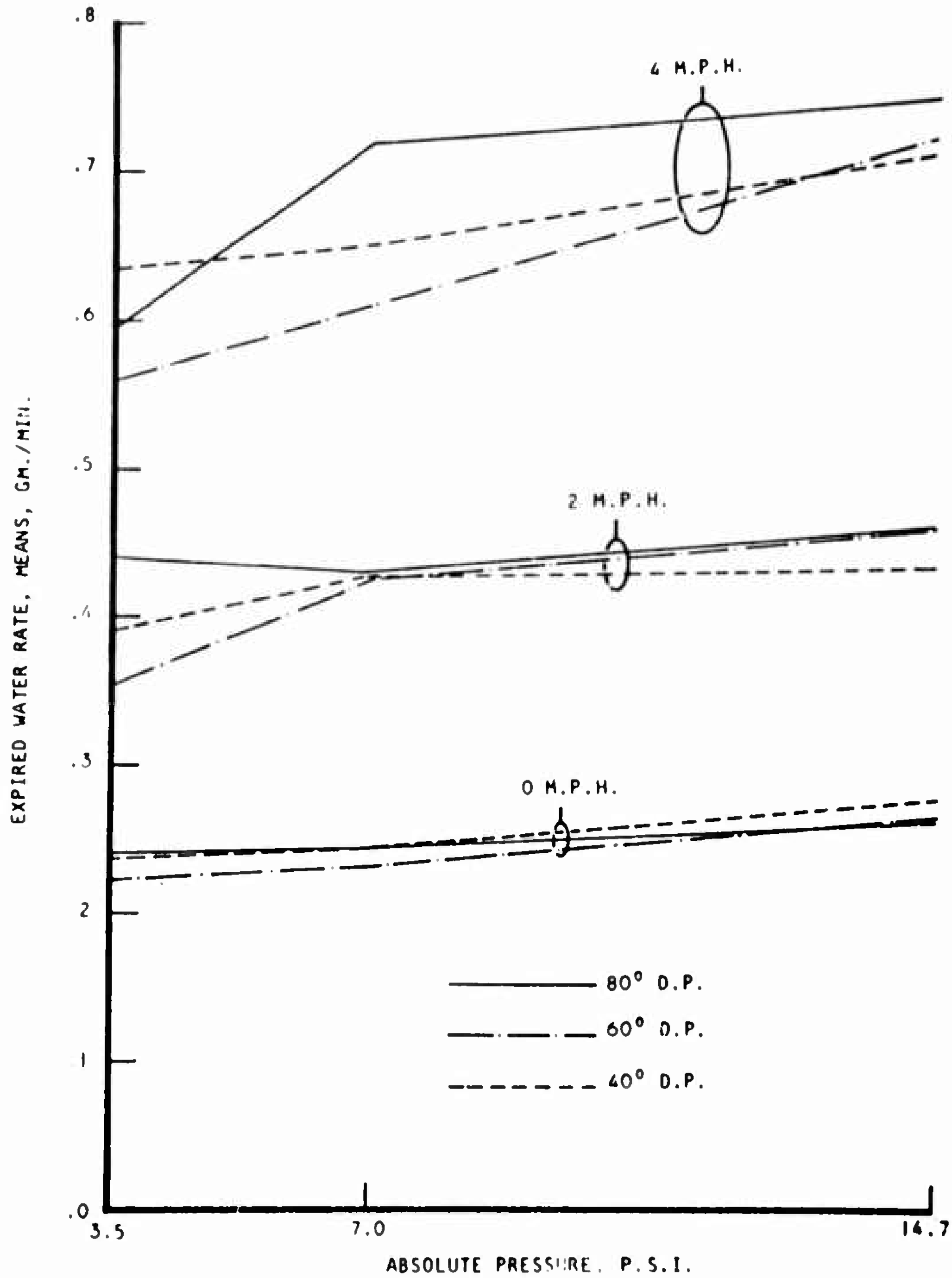


FIGURE 31

Total expired water rate, grams per minute, as a function of absolute pressure, p.s.i., at 95° F. drybulb.

TABLE VI

Minute volume, liters per minute

With independent variables		r
Workrate, m.p.h., at	95° F. drybulb	.96119
	75° F. drybulb	.95684
	55° F. drybulb	.98145
	40° F. dewpoint	.96539
	60° F. dewpoint	.96827
	80° F. dewpoint	.94925
With respiratory water loss, gm./min.		
95° F. drybulb,	80° F. dewpoint	.89345
95° F. drybulb,	60° F. dewpoint	.92068
95° F. drybulb,	40° F. dewpoint	.97468
75° F. drybulb,	60° F. dewpoint	.95306
75° F. drybulb,	40° F. dewpoint	.98265
55° F. drybulb,	40° F. dewpoint	.97094
With respiratory water loss, gm./liter		None ≥ .5

Correlations, as computed, with significant independent variables, and with respiratory water loss, grams per minute and grams per liter, when r ≥ .5.

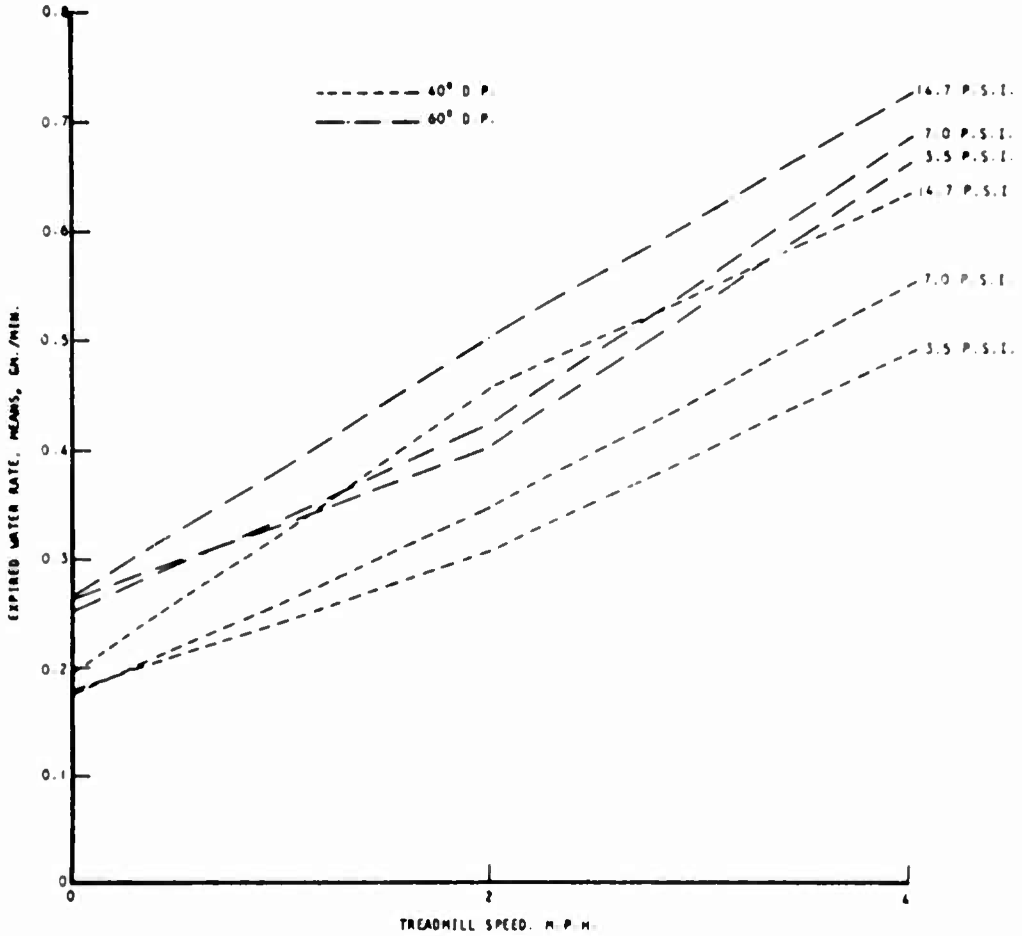


FIGURE 32

Total expired water rate, grams per minute, as a function of treadmill speed, miles per hour, at 75° F. drybulb.

TABLE VII

Expired dewpoint temperature, °F.

With independent variables		r
Dewpoint temp., °F., at	95° F. drybulb	.79000
	75° F. drybulb	.94368
Drybulb temp., °F., at	40° F. dewpoint	.79993
Pressure, p.s.i.a., at	80° F. dewpoint	.89623
With respiratory water loss, gm./min.		None ≥ .5
With respiratory water loss, gm./liter		
95° F. drybulb,	80° F. dewpoint	.86530
95° F. drybulb,	60° F. dewpoint	.76990
95° F. drybulb,	40° F. dewpoint	.88263
75° F. drybulb,	60° F. dewpoint	.89179
75° F. drybulb,	40° F. dewpoint	.86163
55° F. drybulb,	40° F. dewpoint	.81795

Correlations, as computed, with significant independent variables, and with respiratory water loss, grams per minute and grams per liter, when r ≥ .5.

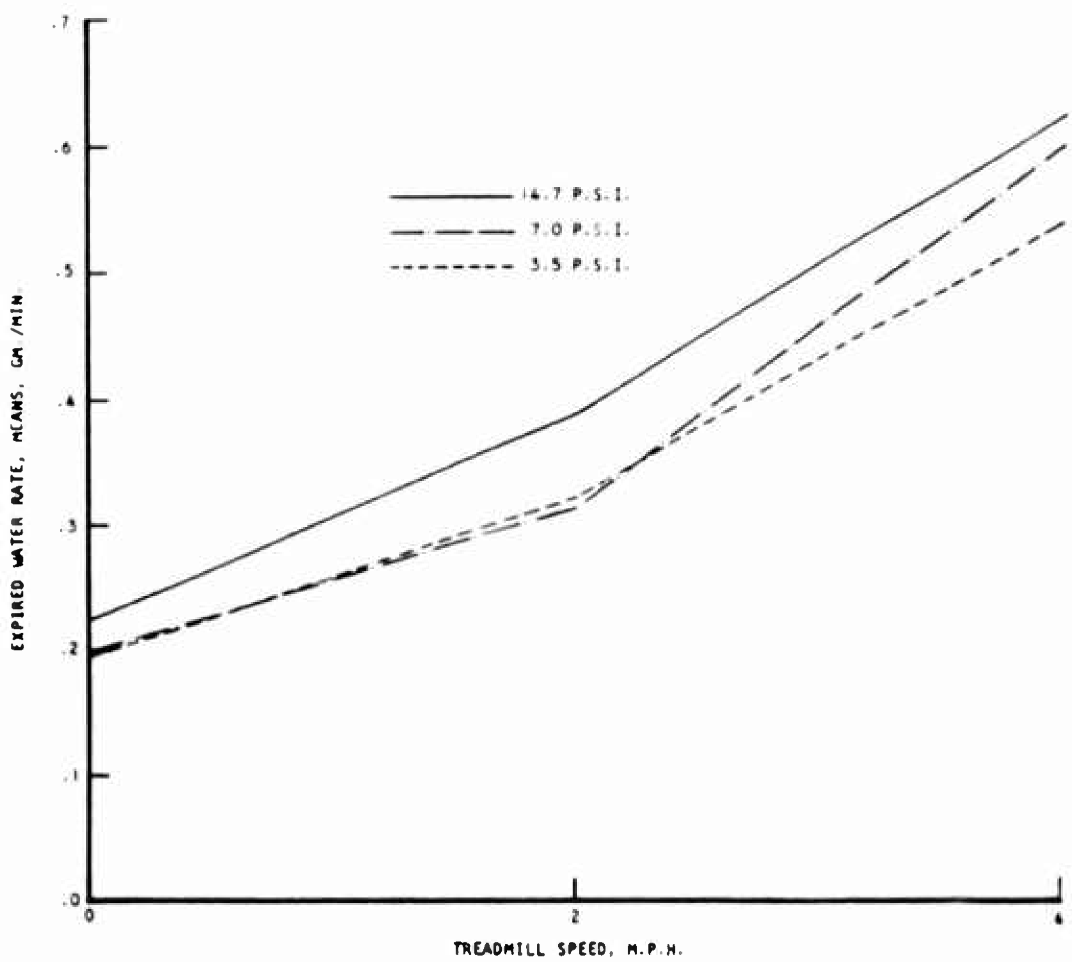


FIGURE 33

Total expired water rate, grams per minute, as a function of treadmill speed, miles per hour, at 55° F. drybulb.

TABLE VIII

Expired drybulb temperature, °F.

With independent variables		r
Dewpoint temp., °F., at	95° F. drybulb	.75339
	75° F. drybulb	.89726
Drybulb temp., °F., at	40° F. dewpoint	.94684
	60° F. dewpoint	.98772
With respiratory water loss, gm./min.		None ≥ .5
With respiratory water loss, gm./liter		
95° F. drybulb, 60° F. dewpoint		.61681

Correlations, as computed, with significant independent variables, and with respiratory water loss, grams per minute and grams per liter, when r ≥ .5.

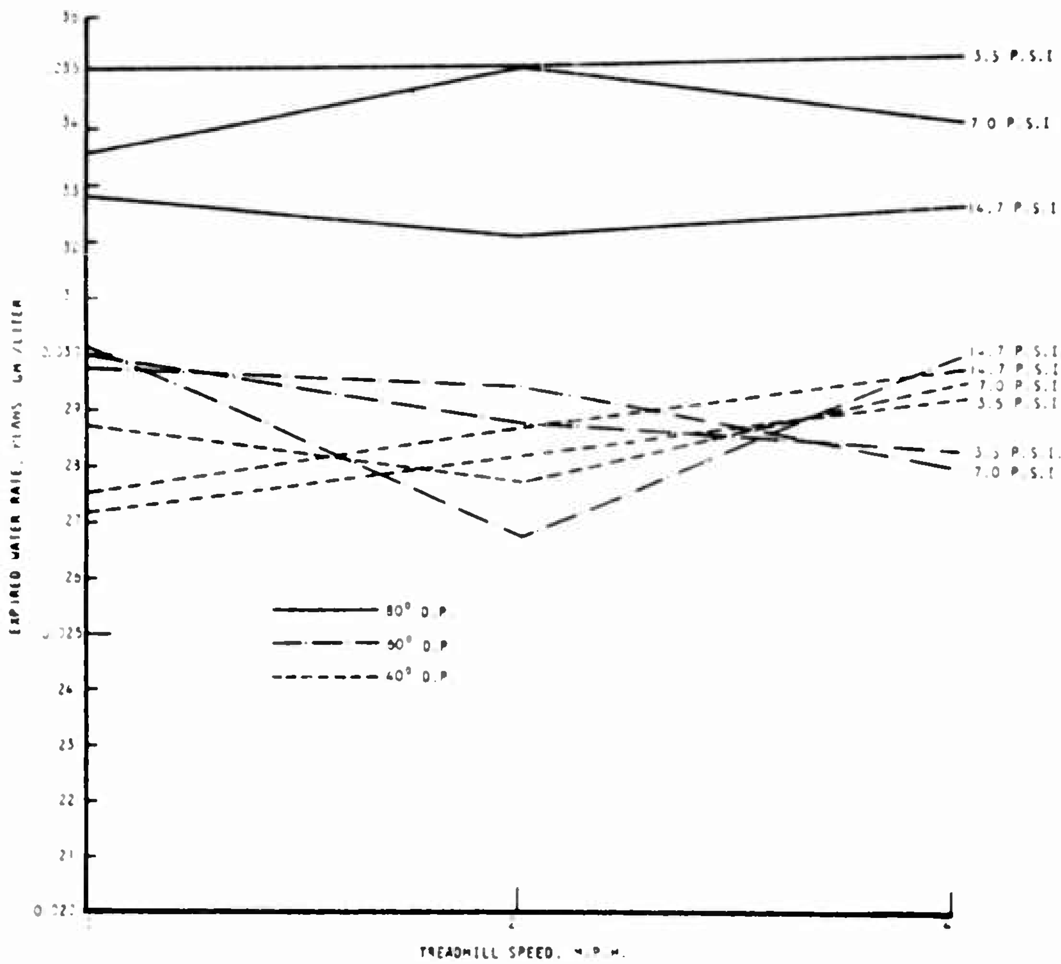


FIGURE 34

Total expired water rate, grams per liter, as a function of treadmill speed, miles per hour, at 95° F. drybulb.

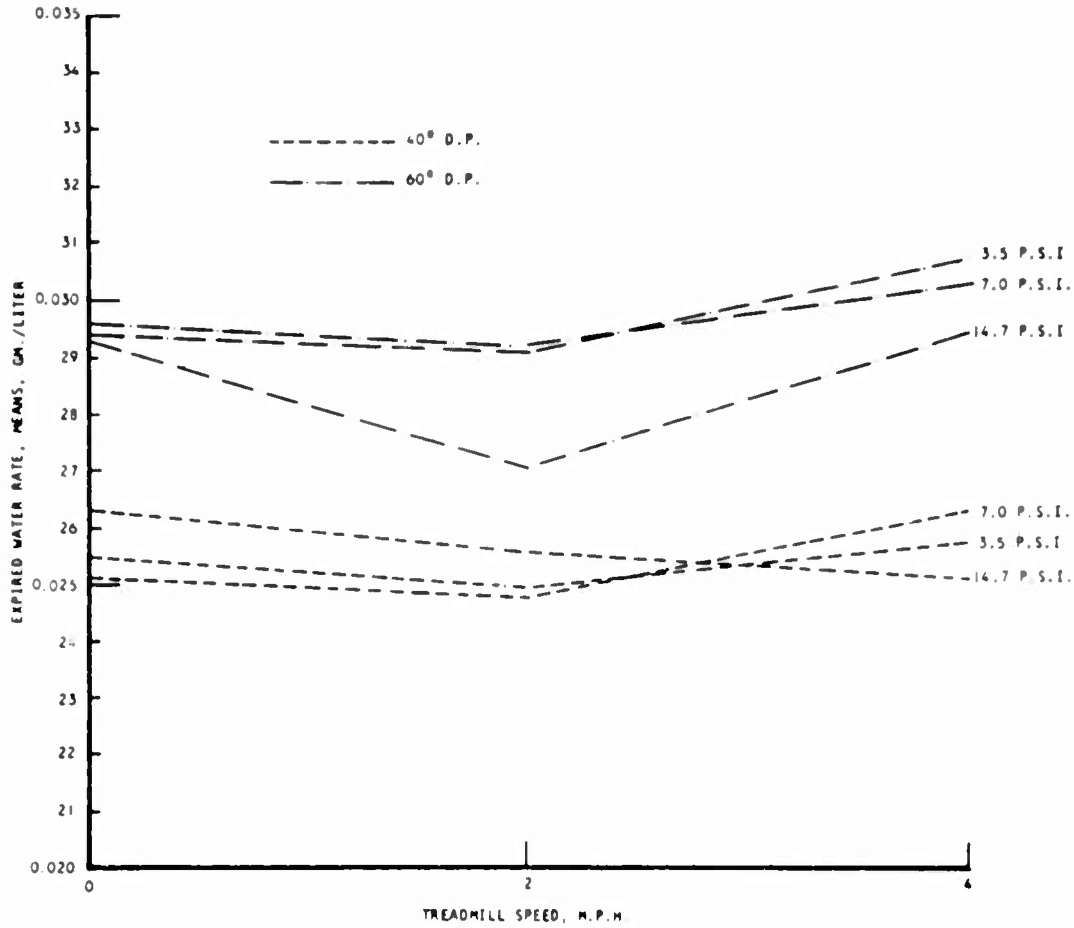


FIGURE 35

Total expired water rate, grams per liter, as a function of treadmill speed, miles per hour, at 75° F. drybulb.

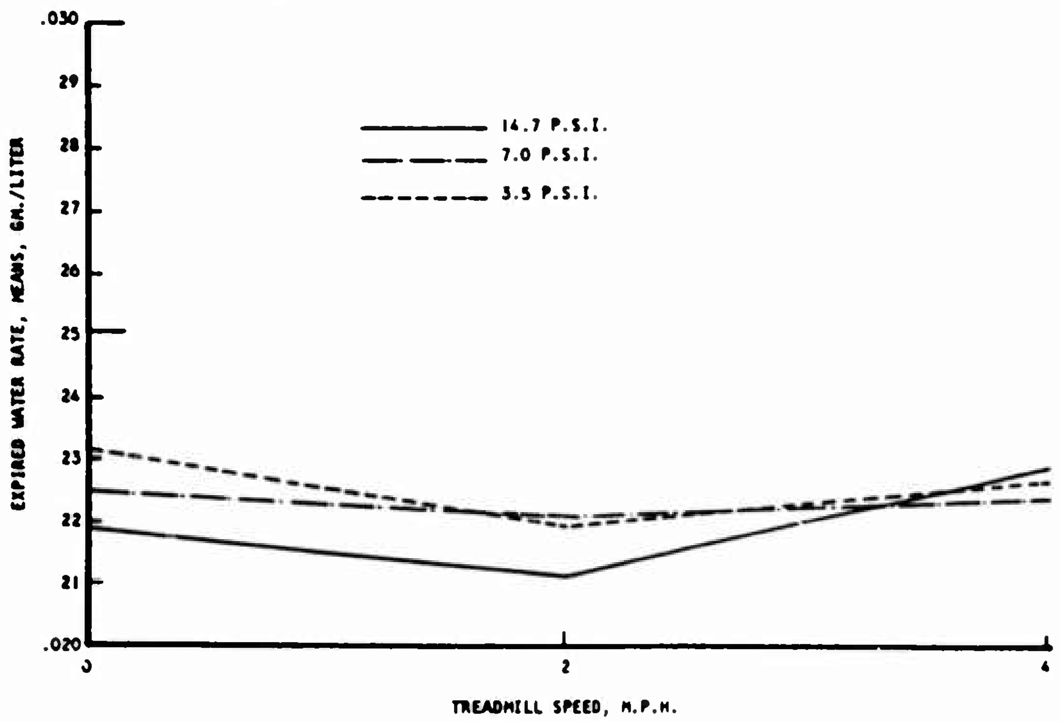


FIGURE 36

Total expired water rate, grams per liter, as a function of treadmill speed, miles per hour, at 55° F. drybulb.

Effects of the daily test sequence

Typical observations during the daily sequence of conditions are shown in figures 59 through 63. The selection of the "typical day" was made randomly. Inspection of the graphs would seem to indicate that the sequence had no effect on rectal temperature, expired dewpoint temperature, or drybulb temperature. Whether or not the sequence of test conditions causes the results seen for minute volume and heart rate is unknown. The temperature graphs suggest that the subjects did recover from the effects of work during the rest periods.

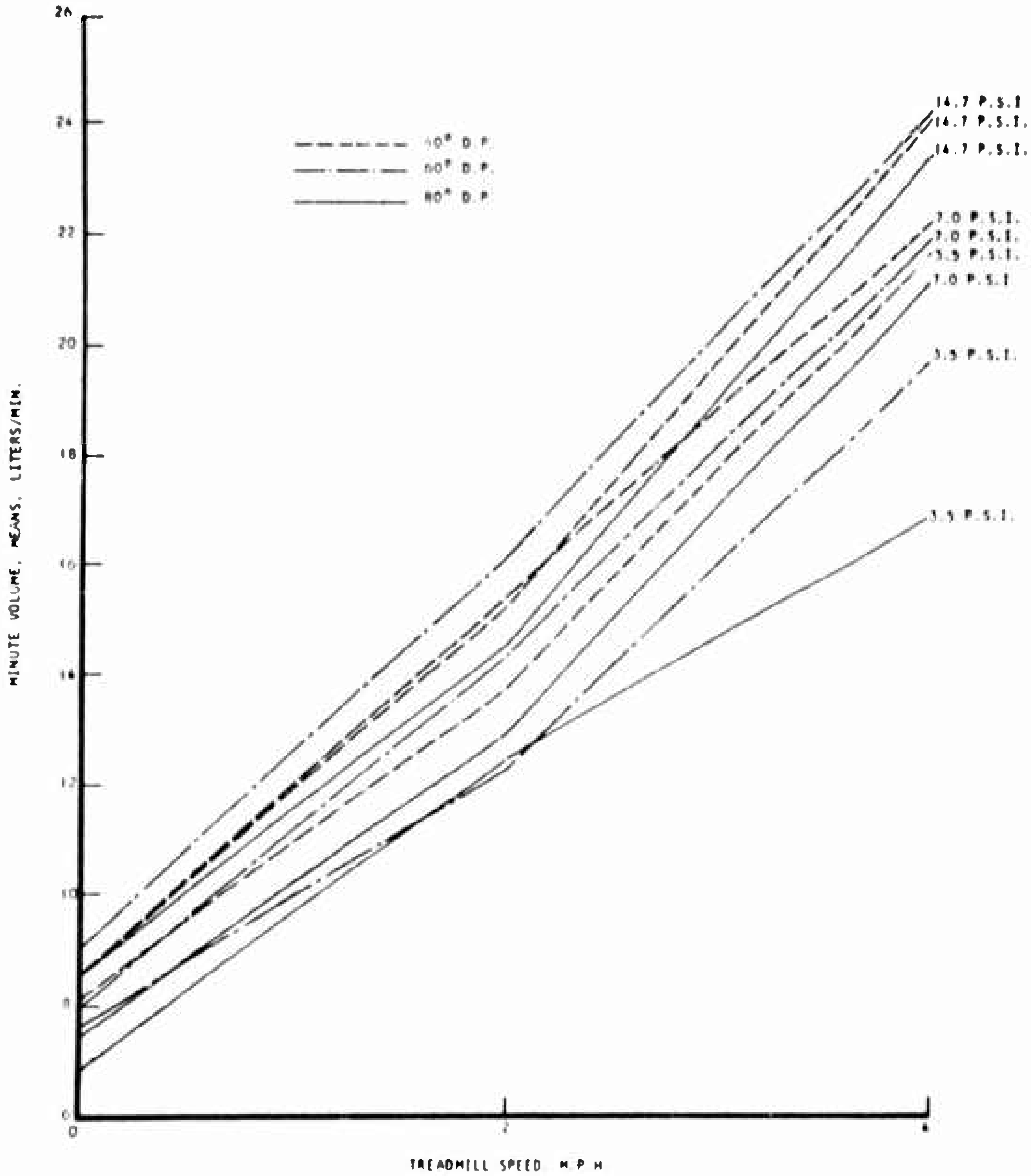


FIGURE 37

Minute volume, liters per minute, as a function of treadmill speed, miles per hour, at 95° F. drybulb.

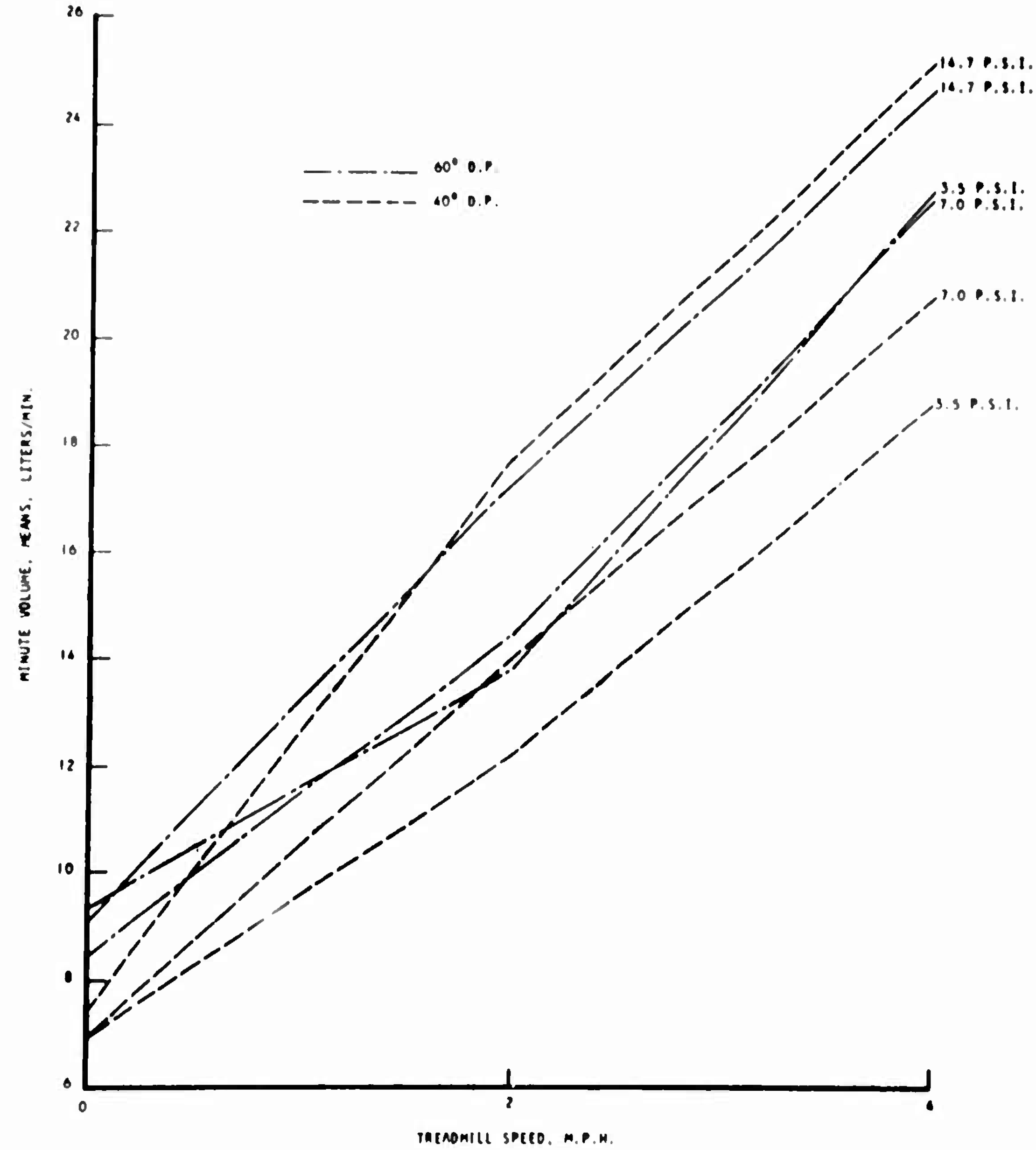


FIGURE 38

Minute volume, liters per minute, as a function of treadmill speed, miles per hour, at 75° F. drybulb.

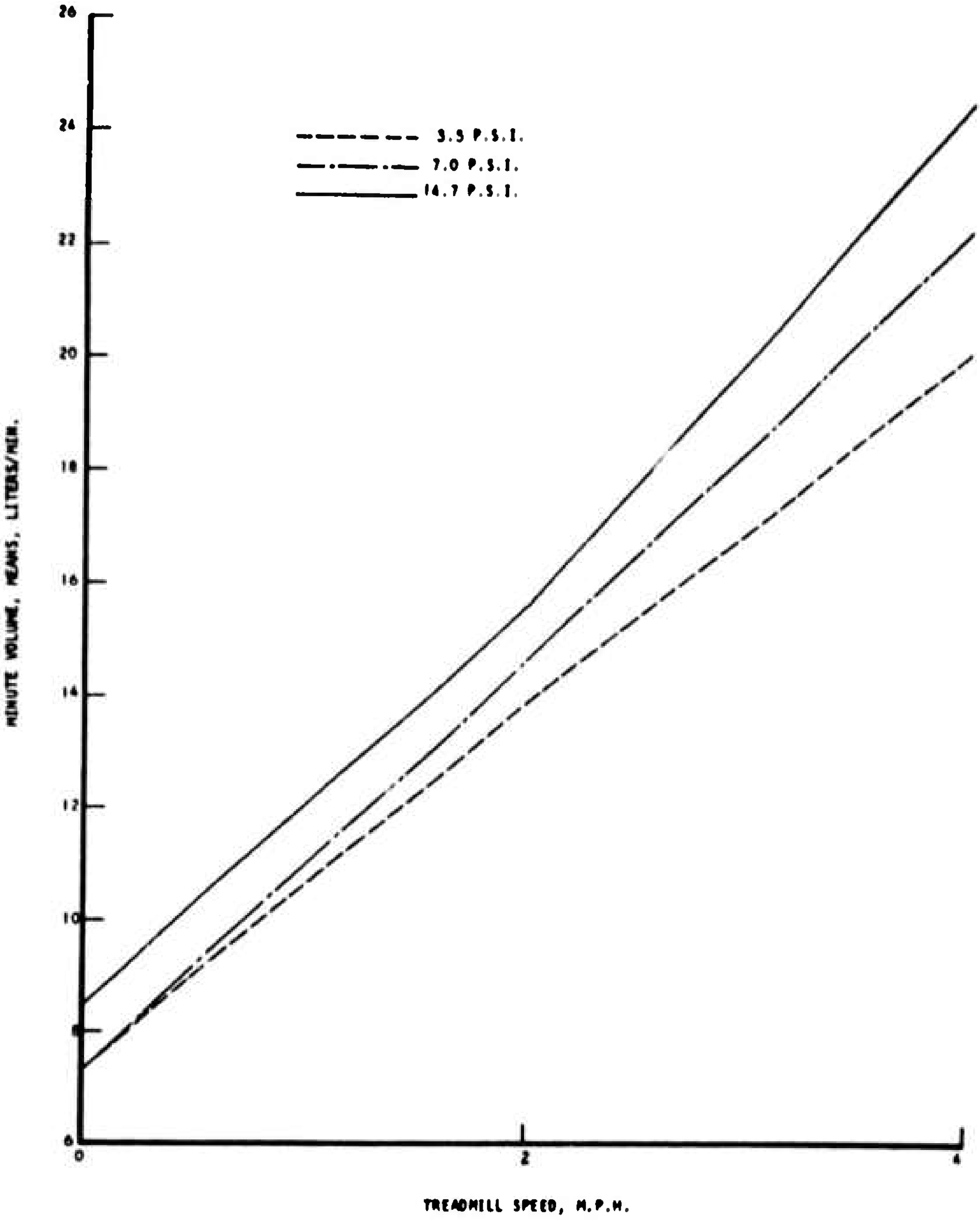


FIGURE 39

Minute volume, liters per minute, as a function of treadmill speed, miles per hour, at 55° F. drybulb.

The phenomenon of decreasing expired drybulb temperatures concurrent with increasing expired dewpoint as work rate is increased is apparent.

In addition, as pointed out previously, minute volume is reduced with reduction in pressure.

V. DISCUSSION OF RESULTS

The most significant finding in this experiment is that respiratory water loss, measured orally in grams per minute, is a direct monotonic function of minute volume for a given set of inhaled dewpoint and drybulb temperature conditions. This relationship is demonstrated by the table of correlations between water loss, in grams per minute, and minute volume, in liters per minute, in table IX. The relationship is shown again in figure 64, which presents respiratory water loss as a function of minute volume for all work rates and pressures. This figure also depicts the pronounced effect of inhaled dewpoint

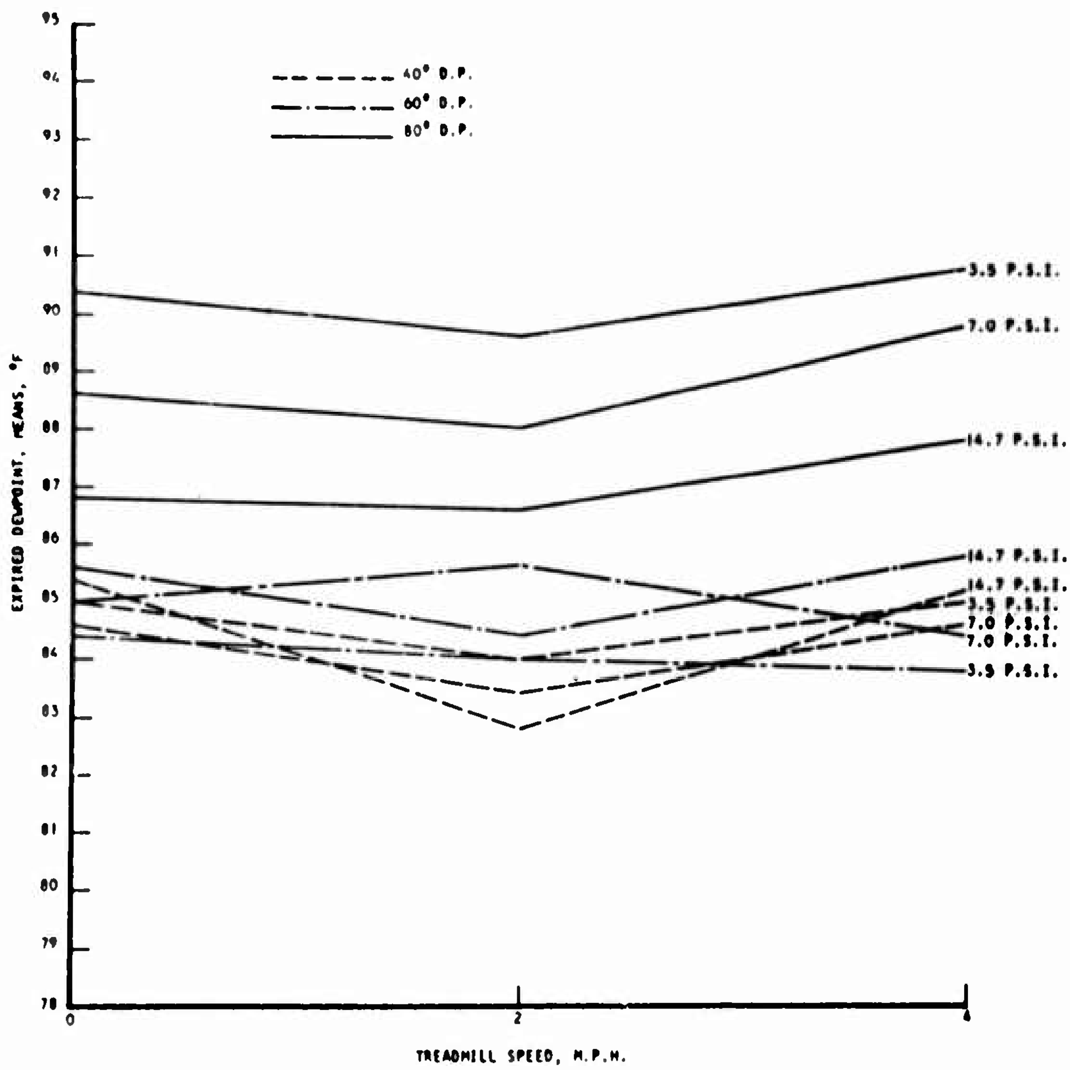


FIGURE 40

Expired dewpoint temperature, °F., as a function of treadmill speed, miles per hour, at 95° F. drybulb.

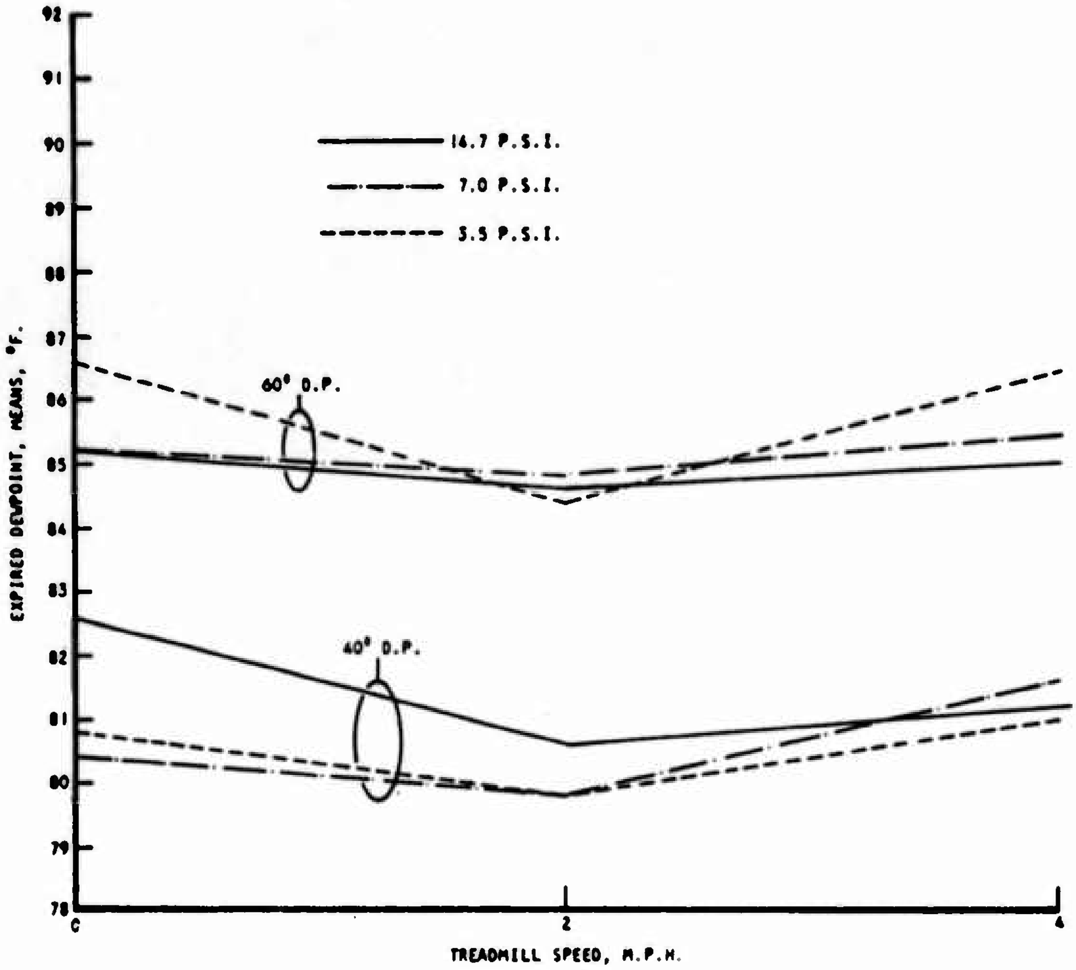


FIGURE 41

Expired dewpoint temperature, °F., as a function of treadmill speed, miles per hour, at 75° F. drybulb.

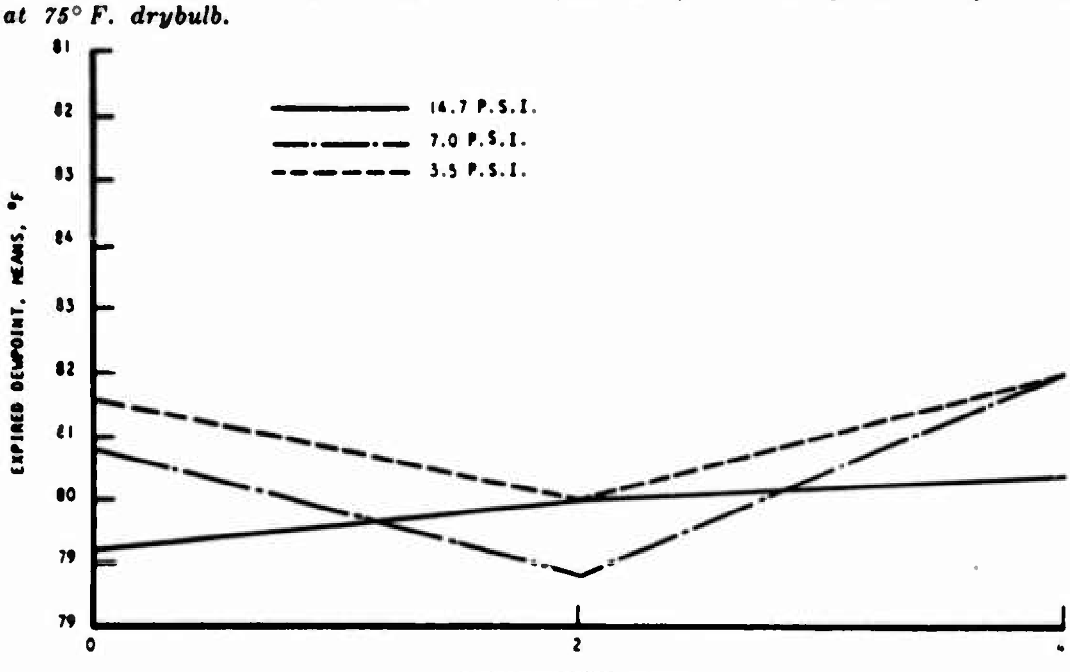


FIGURE 42

Expired dewpoint temperature, °F., as a function of treadmill speed, miles per hour, at 55° F. drybulb.

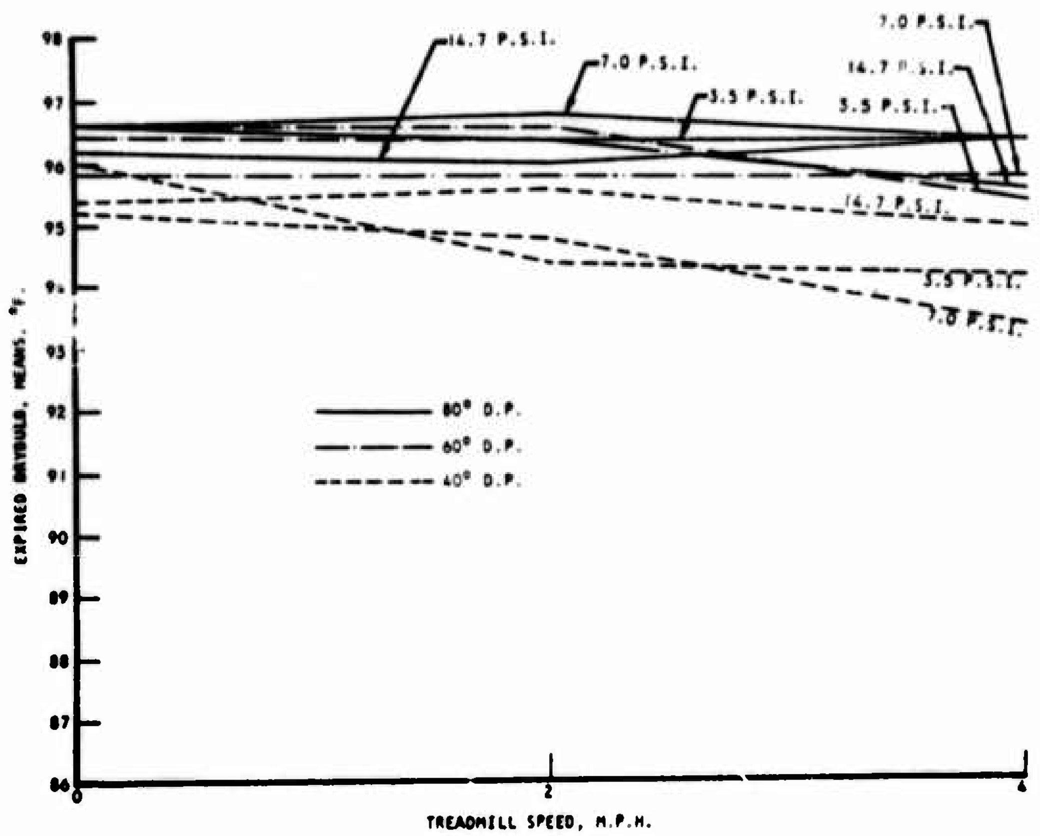


FIGURE 43

Expired drybulb temperature, °F., as a function of treadmill speed, miles per hour, at 95° F. drybulb.

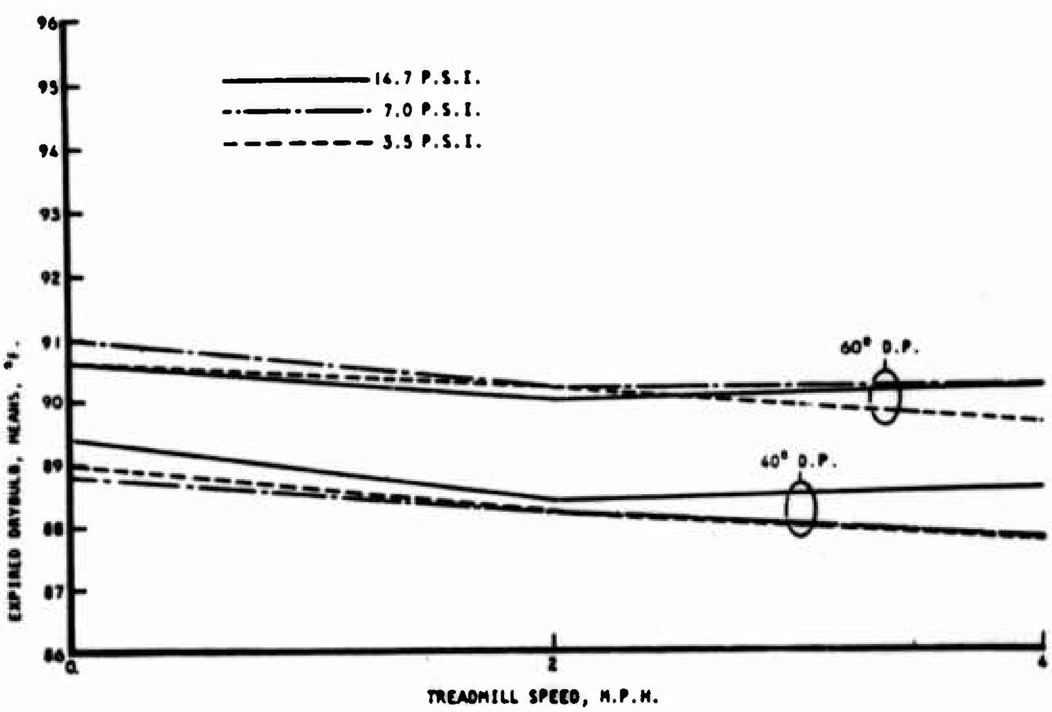


FIGURE 44

Expired drybulb temperature, °F., as a function of treadmill speed, miles per hour, at 75° F. drybulb.

temperature on respiratory water loss and the variations in respiratory water loss with inhaled drybulb temperature. Figure 64 illustrates this general relationship when minute volume is converted to STP conditions. With minute volume at STP, respiratory water loss can be estimated with knowledge of inhaled dewpoint, pressure, and minute volume.

The observation that respiratory water loss decreases at reduced pressure for subjects breathing oxygen by mouth also is significant. In view of the relationship between respiratory water loss and minute volume discussed above, it is concluded this effect of reduced pressure is brought about by the reduction of minute volume. This is substantiated by the observation that respiratory water loss, calculated in grams per liter, does not vary significantly with pressure, while minute volume decreases with decreased pressure.

Reduction in minute volume at reduced pressure was predicted by Jaeger and Otis (27) on the basis of examples given by Fenn (28). Their prediction was based on the fact that at reduced pressure less work is required for breathing and there is less turbulence in the airways.

The work of Marshall and Specht (21) is probably most applicable to this report because they made observations at reduced barometric pressure. These investigators measured respiratory water loss from the nose at a simulated altitude of 30,000 ft. and at approximate sea level conditions. Their subjects breathed supposedly pure (unmeasured) oxygen for experimental modes lasting no more than 5 minutes. Although their data may lack quantitative precision because of a primitive technic for measuring dewpoints and an assumption that exhaled gas is 80% saturated at 32.2° C., their results nevertheless are valuable for comparative discussion.

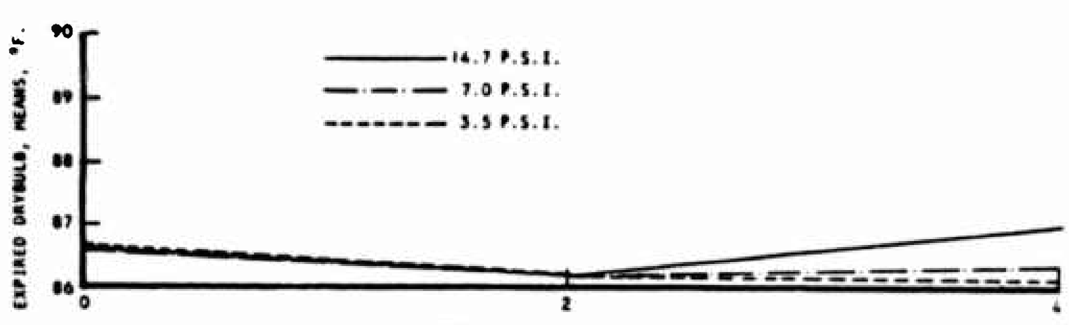


FIGURE 45

Expired drybulb temperature, °F., as a function of treadmill speed, miles per hour, at 55° F. drybulb.

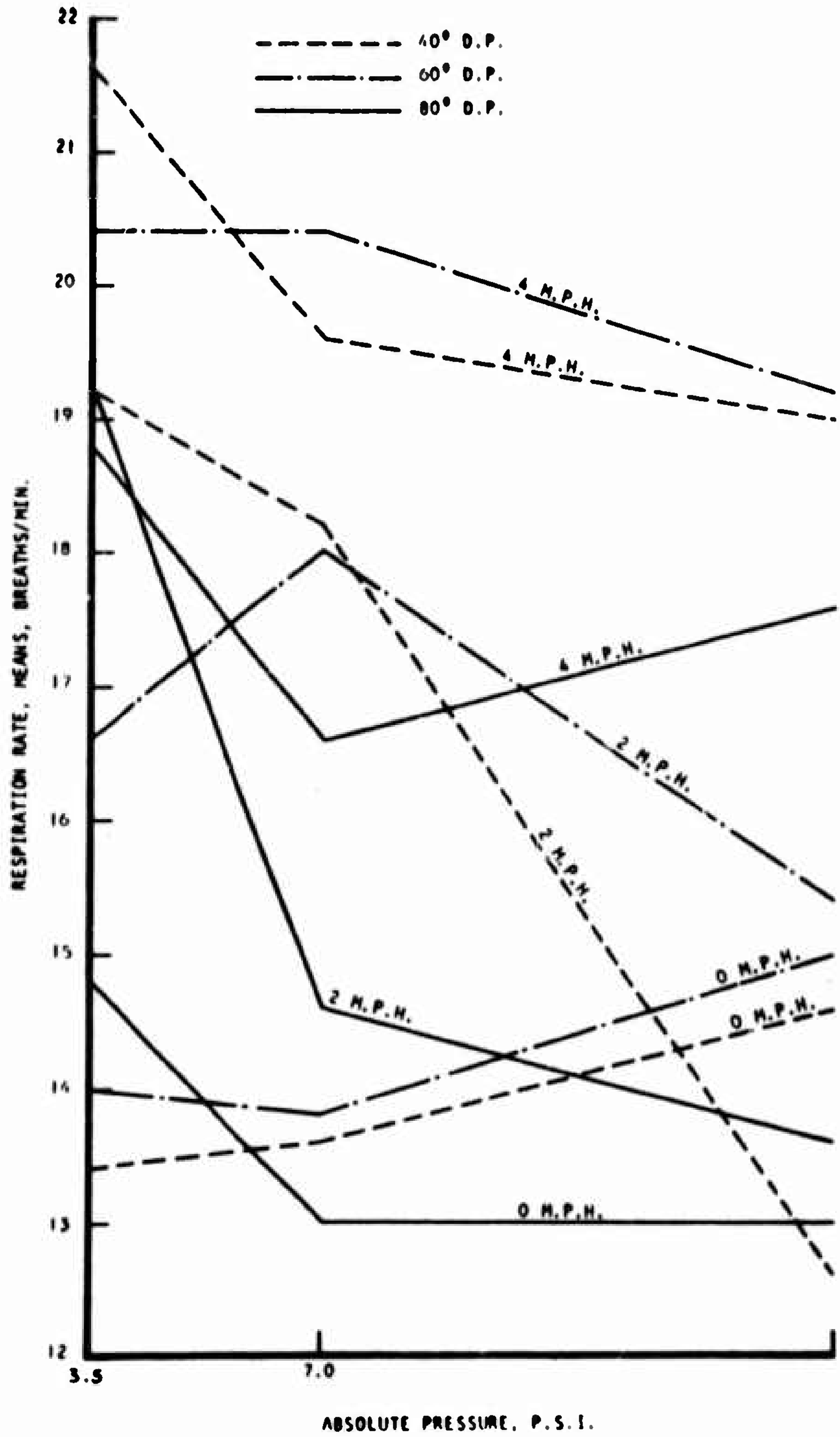


FIGURE 46

Respiration rate, breaths per minute, as a function of absolute pressure, p.s.i., at 95° F. drybulb.

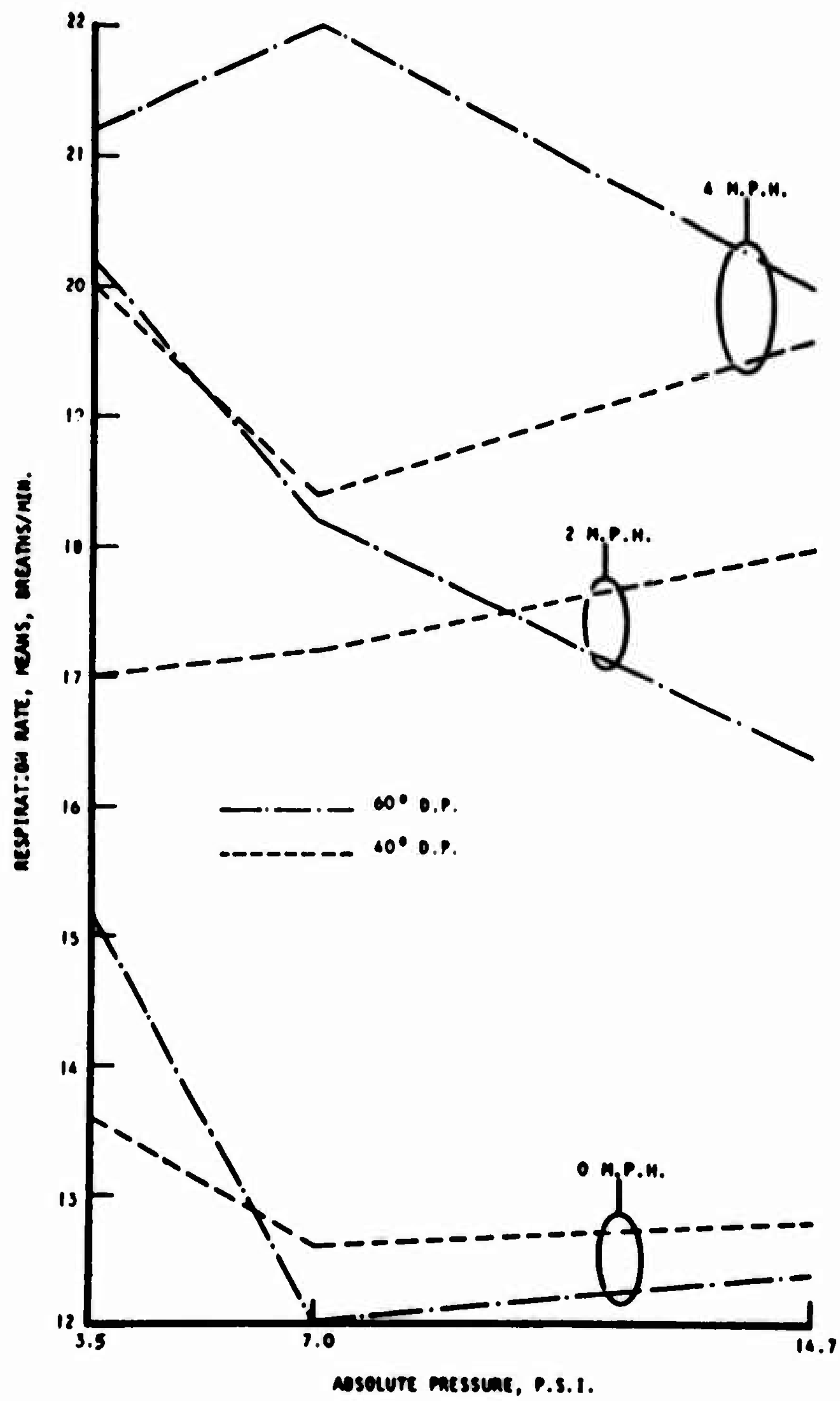


FIGURE 47

Respiration rate, breaths per minute, as a function of absolute pressure, p.s.i., at 75° F. drybulb.

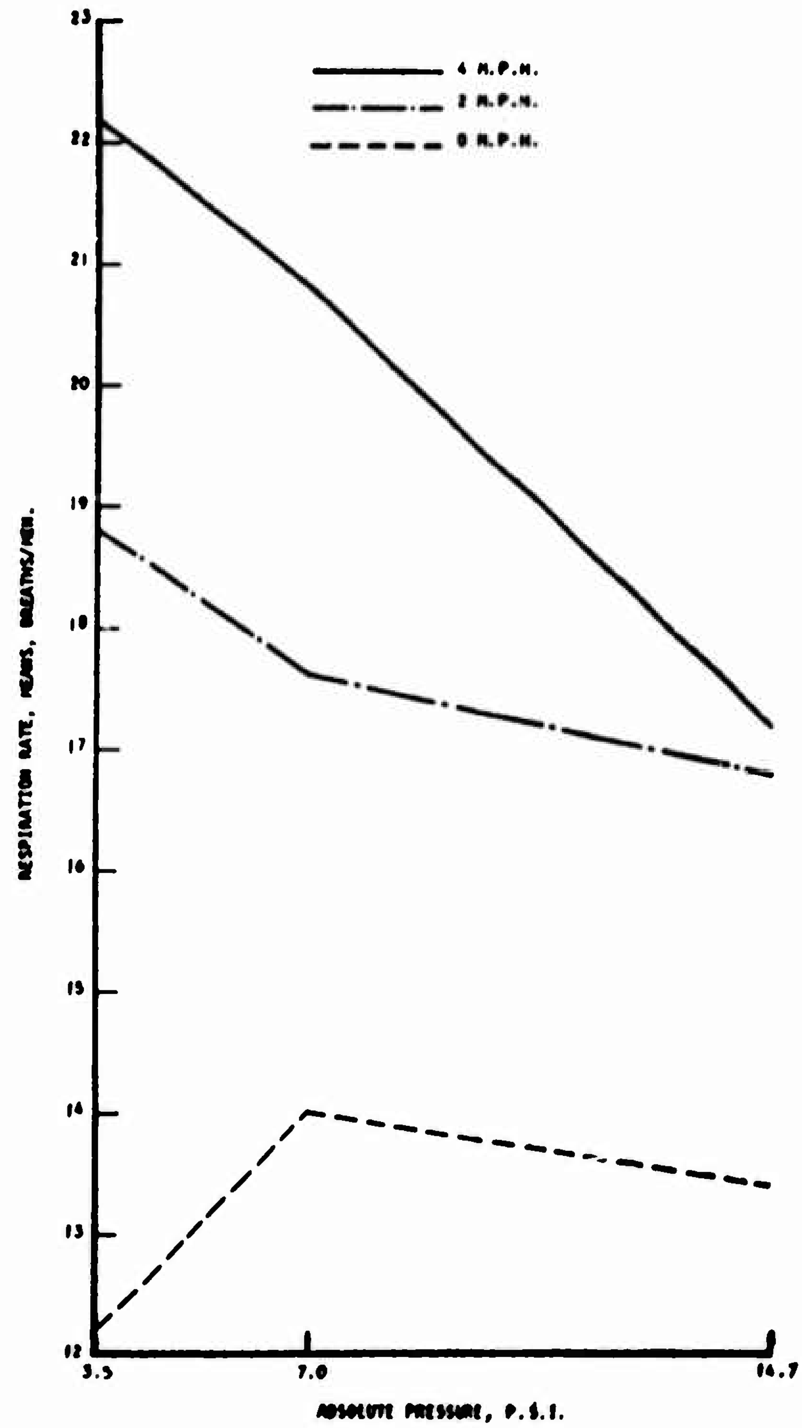


FIGURE 48

Respiration rate, breaths per minute, as a function of absolute pressure, p.s.i, at 55° F. drybulb.

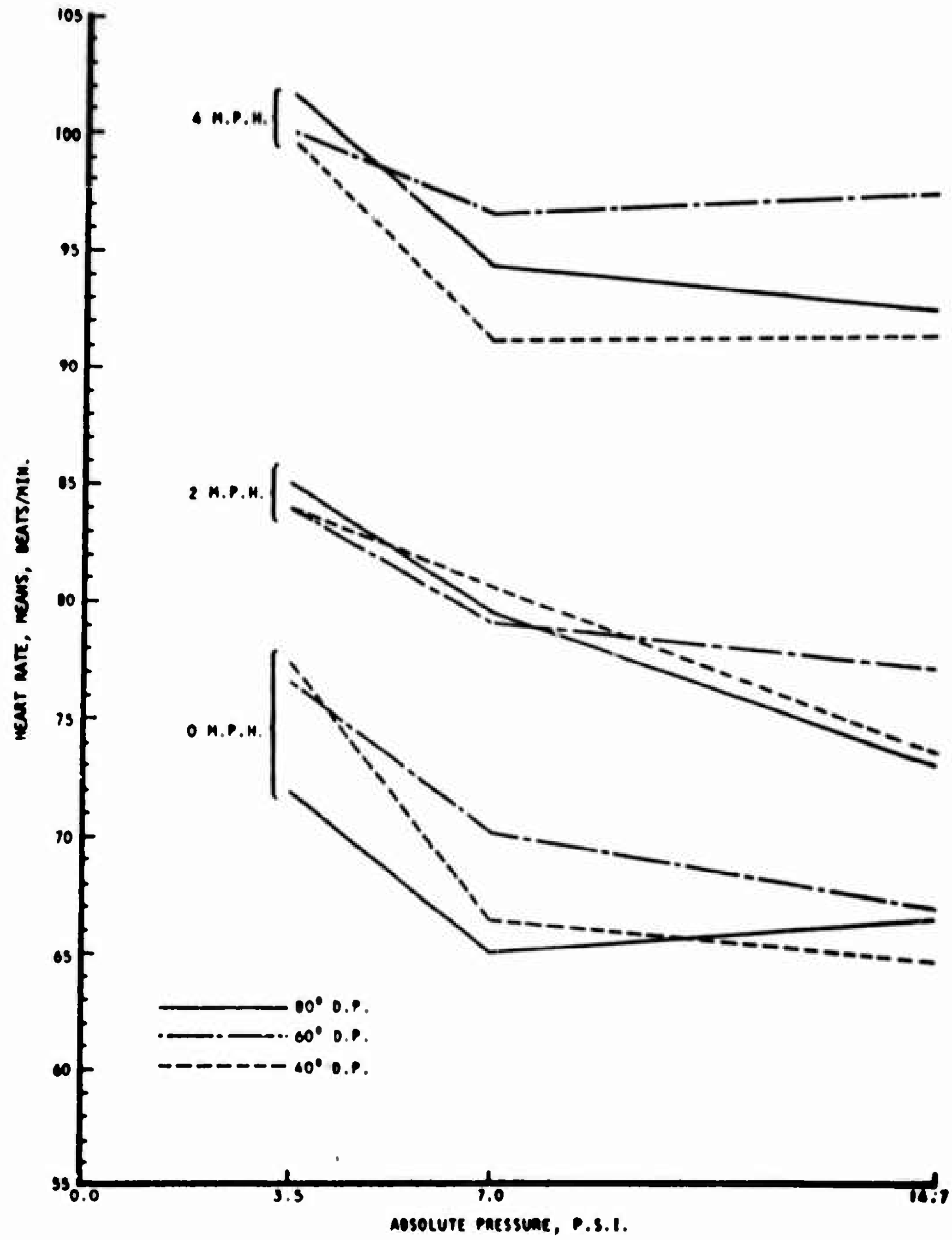


FIGURE 49

Heart rate, beats per minute, as a function of absolute pressure, p.s.i., at 95° F. drybulb.

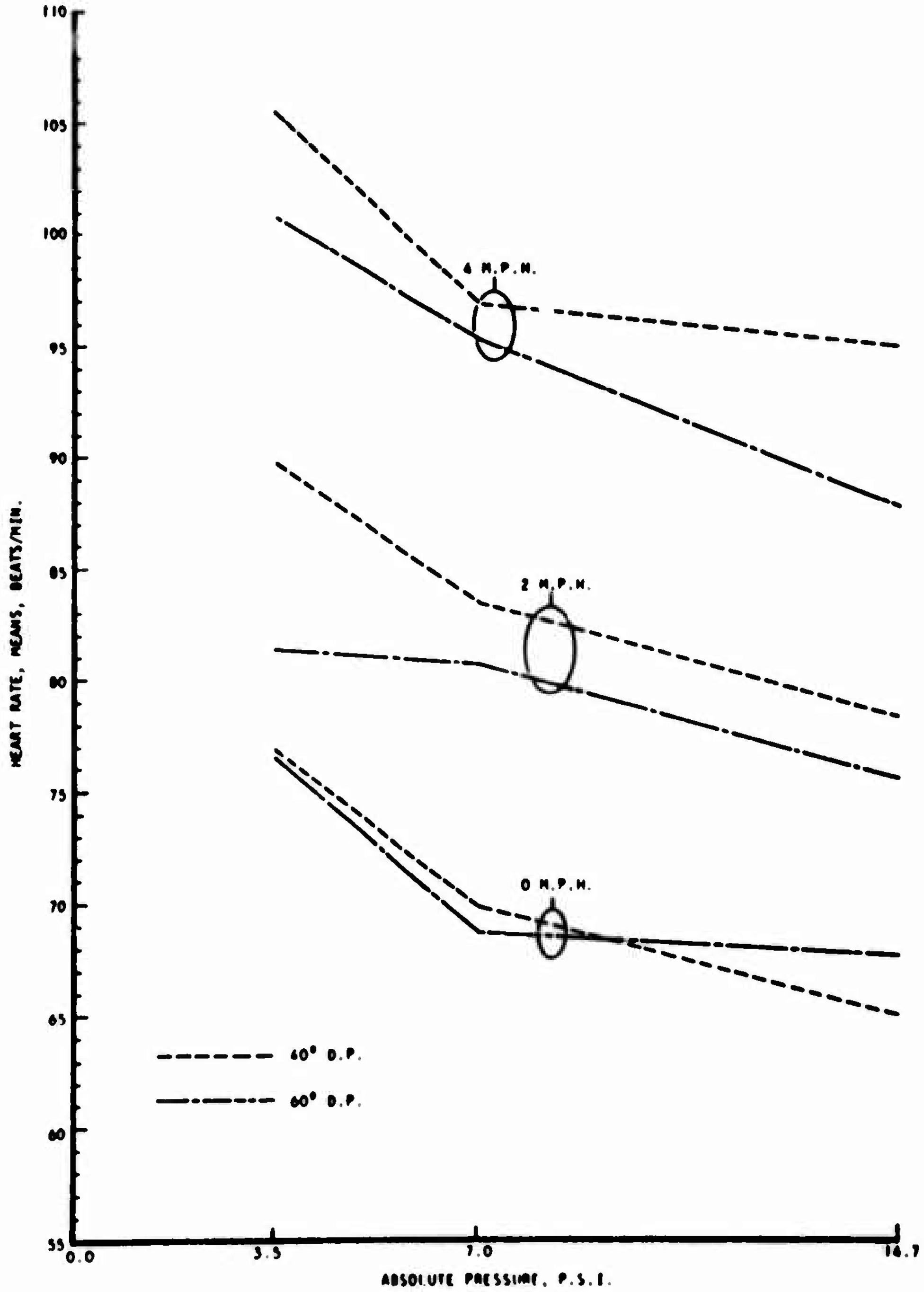


FIGURE 50

Heart rate, beats per minute, as a function of absolute pressure, p.s.i., at 75° F. drybulb.

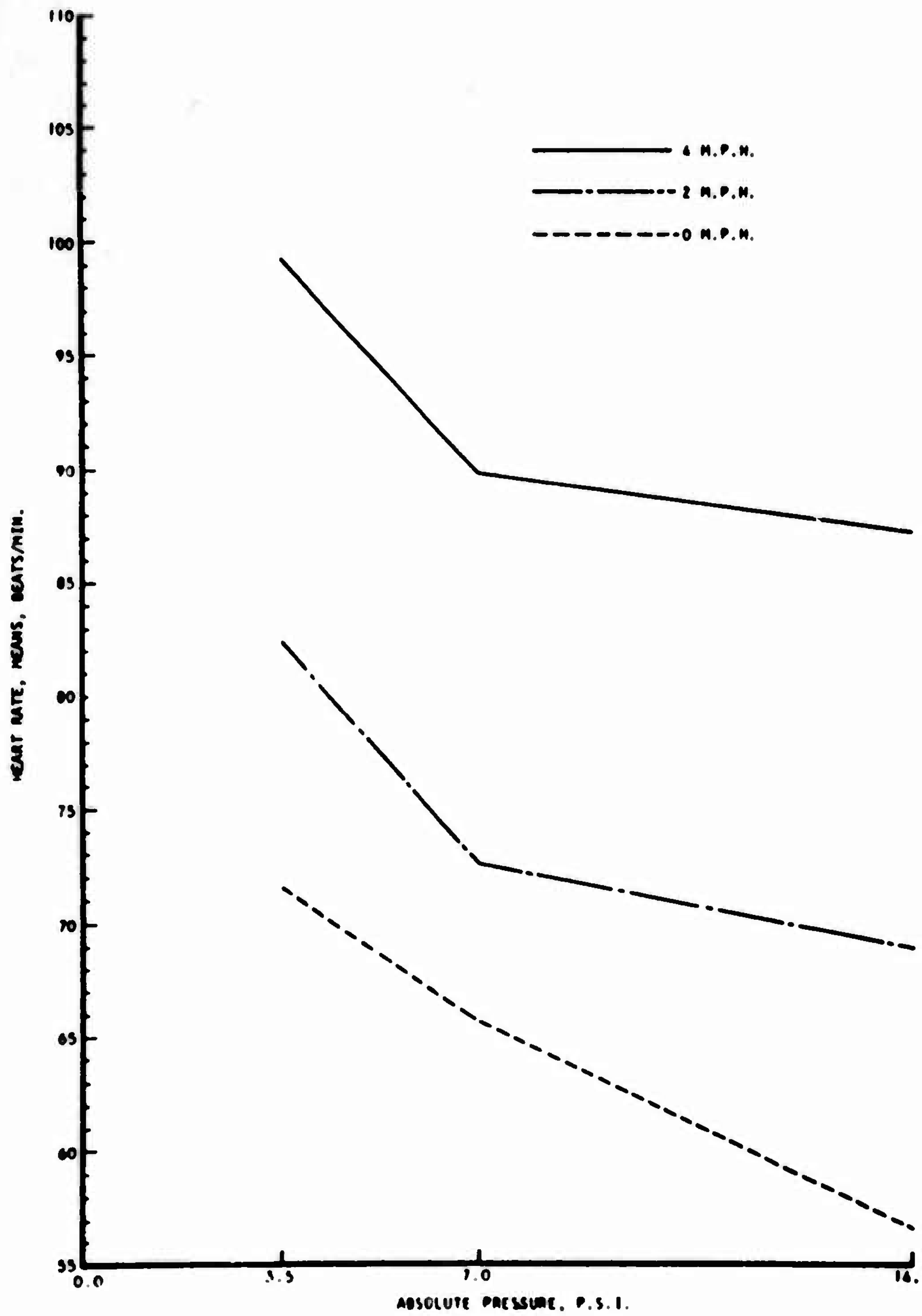


FIGURE 51

Heart rate, beats per minute, as a function of absolute pressure, p.s.i., at 55° F. drybulb.

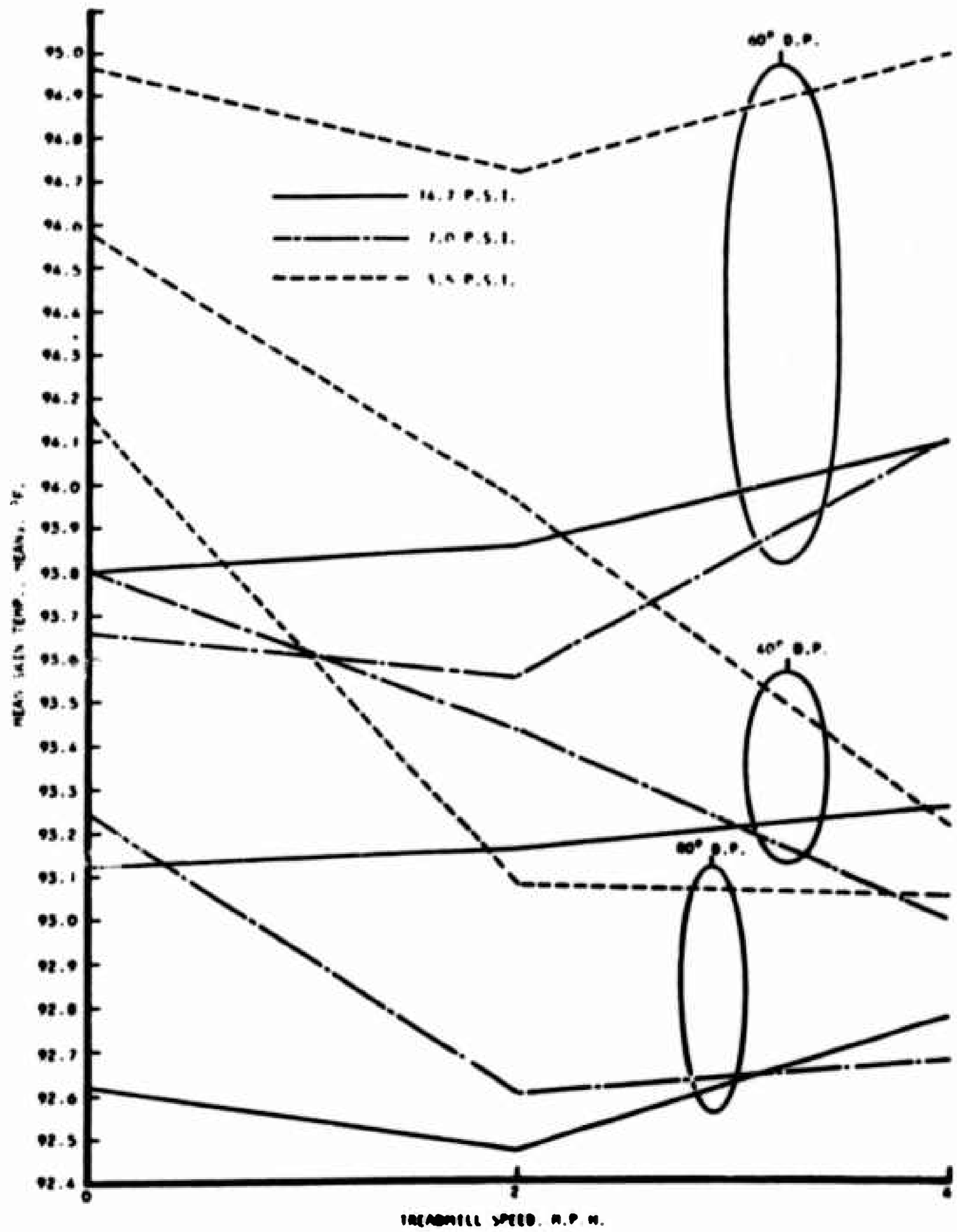


FIGURE 52

Mean skin temperature, °F., as a function of treadmill speed, miles per hour, at 95° F. drybulb.

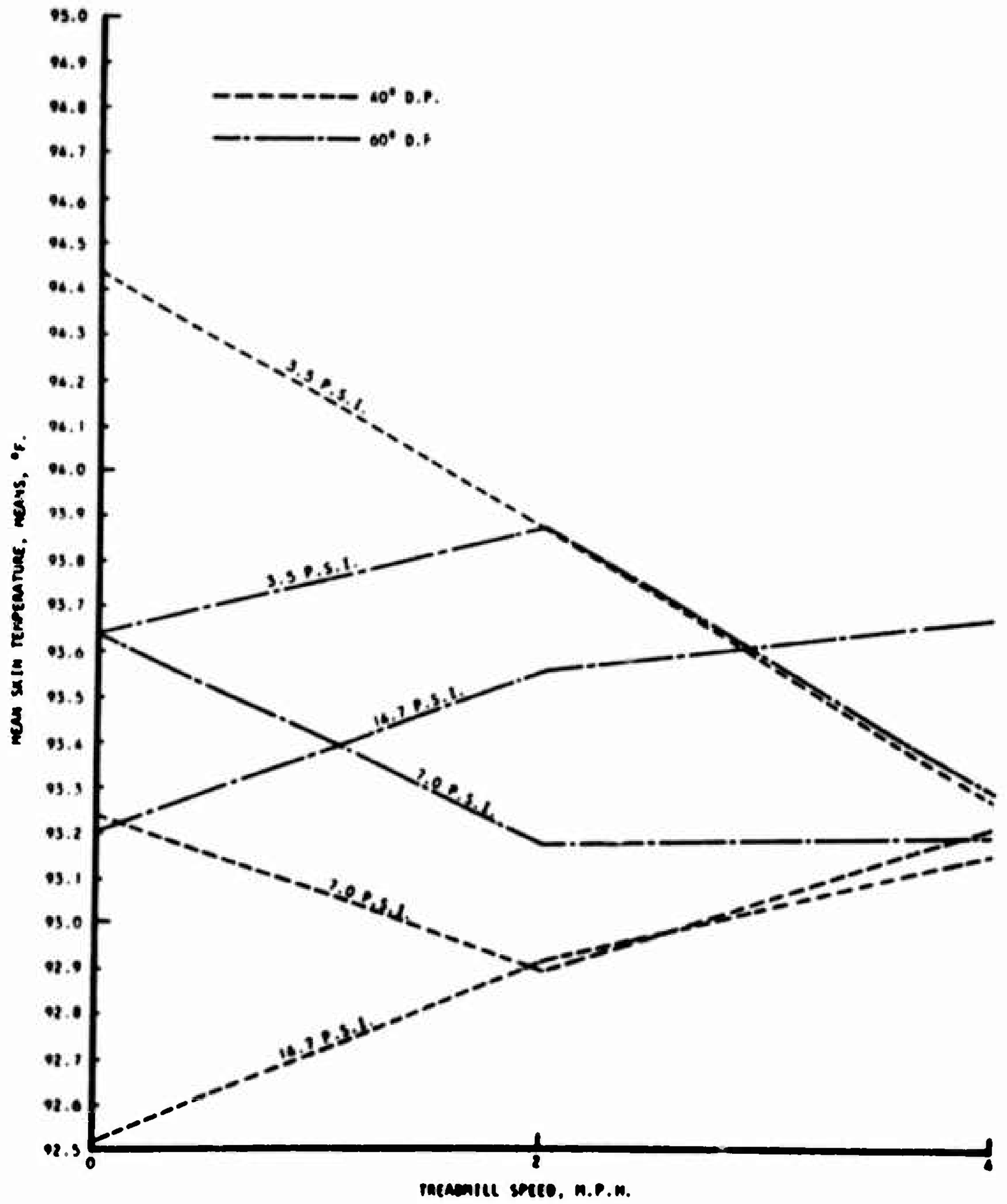


FIGURE 53

Mean skin temperature, °F., as a function of treadmill speed, miles per hour, at 75° F. drybulb.

TABLE IX

Correlation between water loss in grams per minute and minute volume in liters per minute

Drybulb temperature, °F.	Dewpoint temperature, °F.* 40°	60°	80°
95°	0.991	0.921	0.883
75°	0.983	0.953	
55°	0.972		

*For all work rates and pressures.

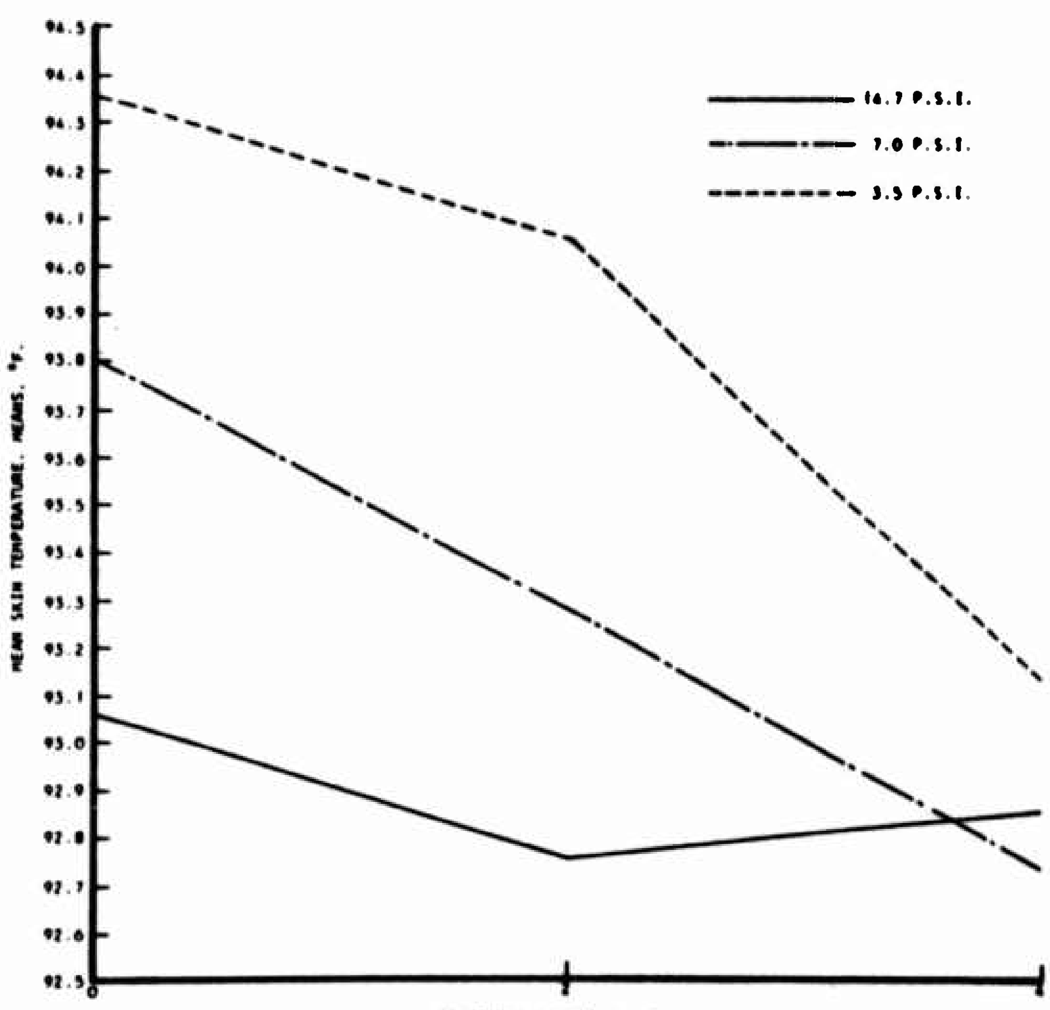


FIGURE 54

Mean skin temperature, °F., as a function of treadmill speed, miles per hour, at 55° F. drybulb.

The mean water loss difference between sea level and 30,000 ft. reported by these investigators was 0.05 gm./min. This figure represented a decrease in water loss with altitude and was of the same order of magnitude as the values determined in the present experiment; however, there is a considerable discrepancy in absolute quantity. The approximate range of means obtained in the present study was 0.07 to 0.21 gm./min. for the resting condition, varying with the factors of inspired dewpoint and drybulb. Also, these lower values were observed at elevated inspired dewpoint temperatures, while the results of Marshall and Specht were obtained for supposedly dry inspired gas. Dry oxygen was not used in the present experiments, but extrapolation indicates that under such conditions the respired water loss would have been perhaps as high as 0.30 gm./min.

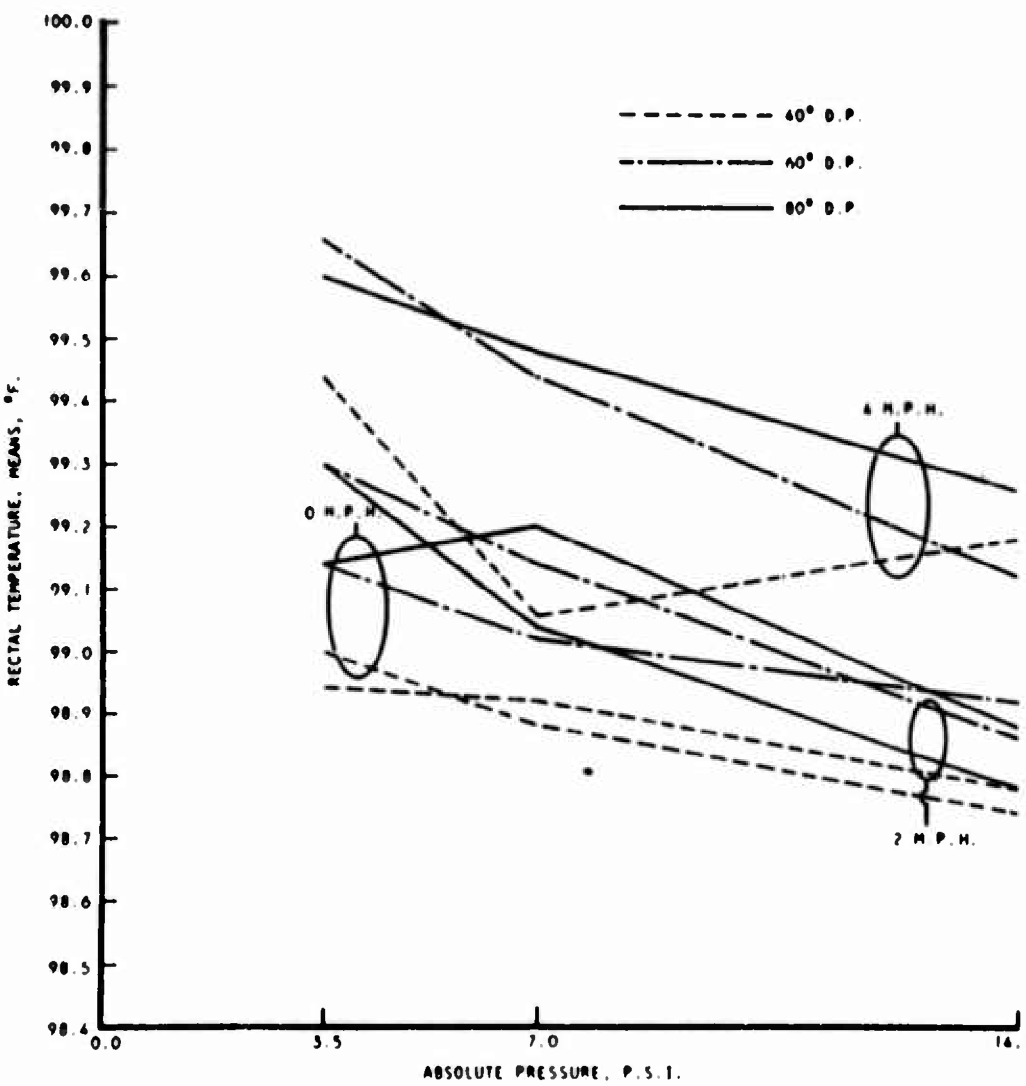


FIGURE 55

Rectal temperature, °F., as a function of absolute pressure, p.s.i., at 95° F. drybulb.

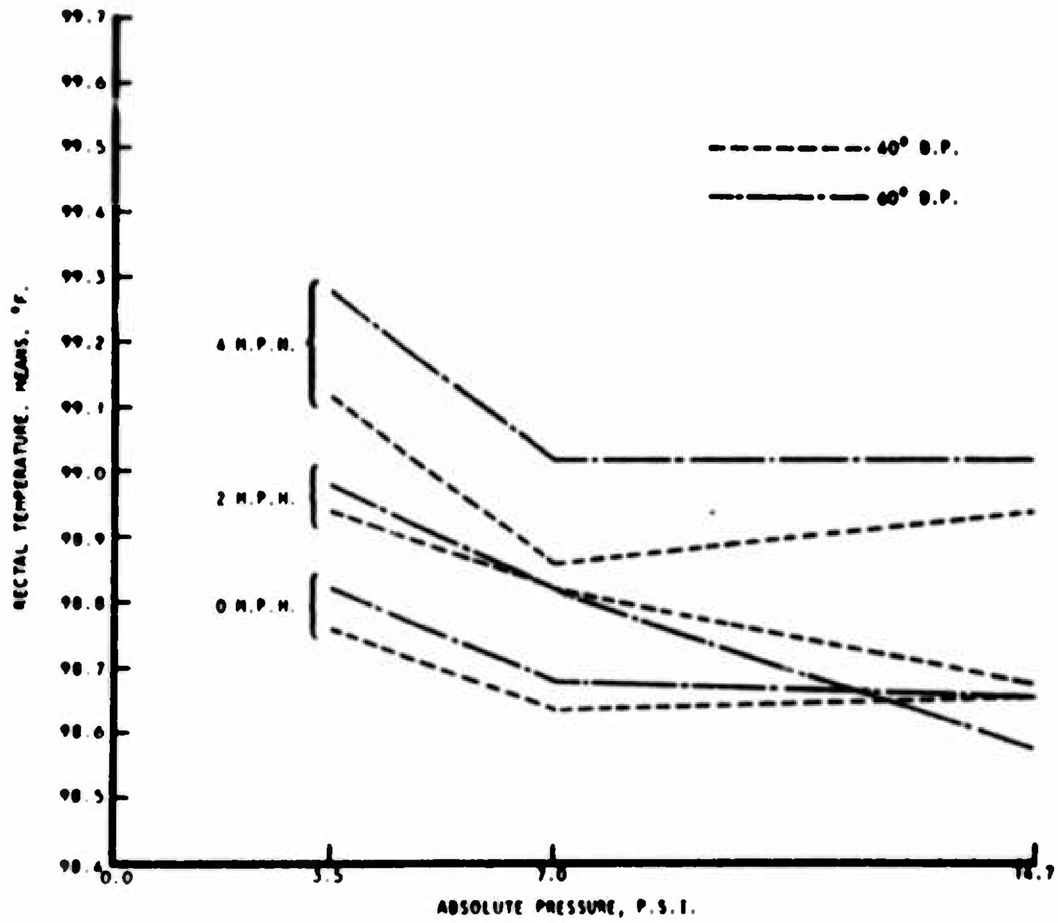


FIGURE 56

Rectal temperature, °F., as a function of absolute pressure, p.s.i., at 75° F. drybulb.

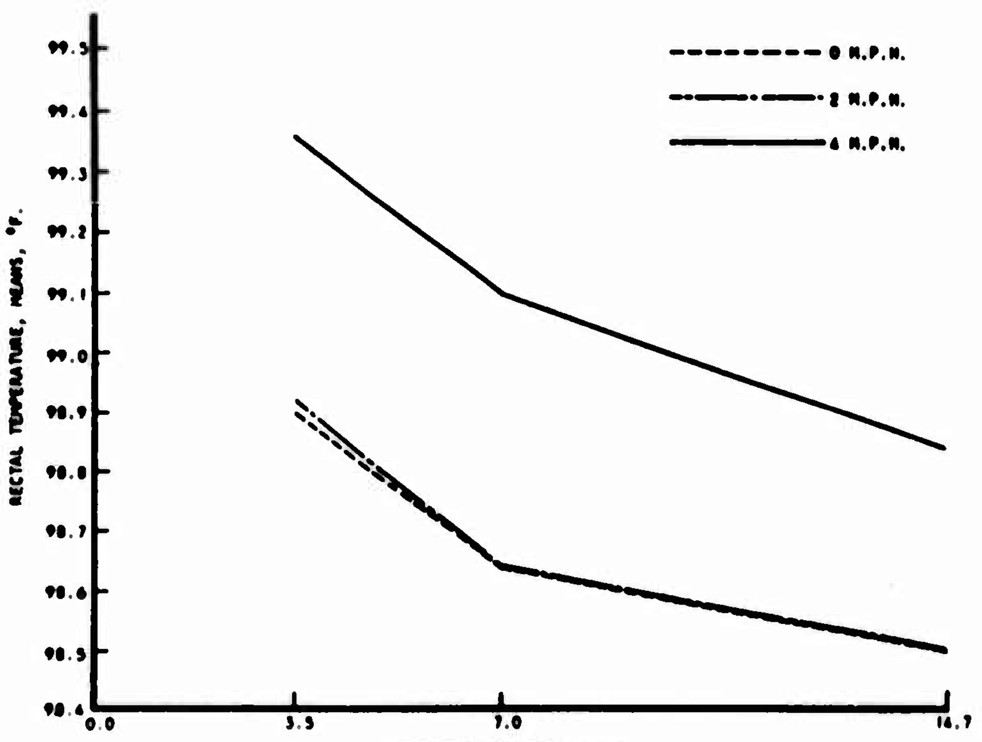


FIGURE 57

Rectal temperature, °F., as a function of absolute pressure, p.s.i., at 55° F. drybulb.

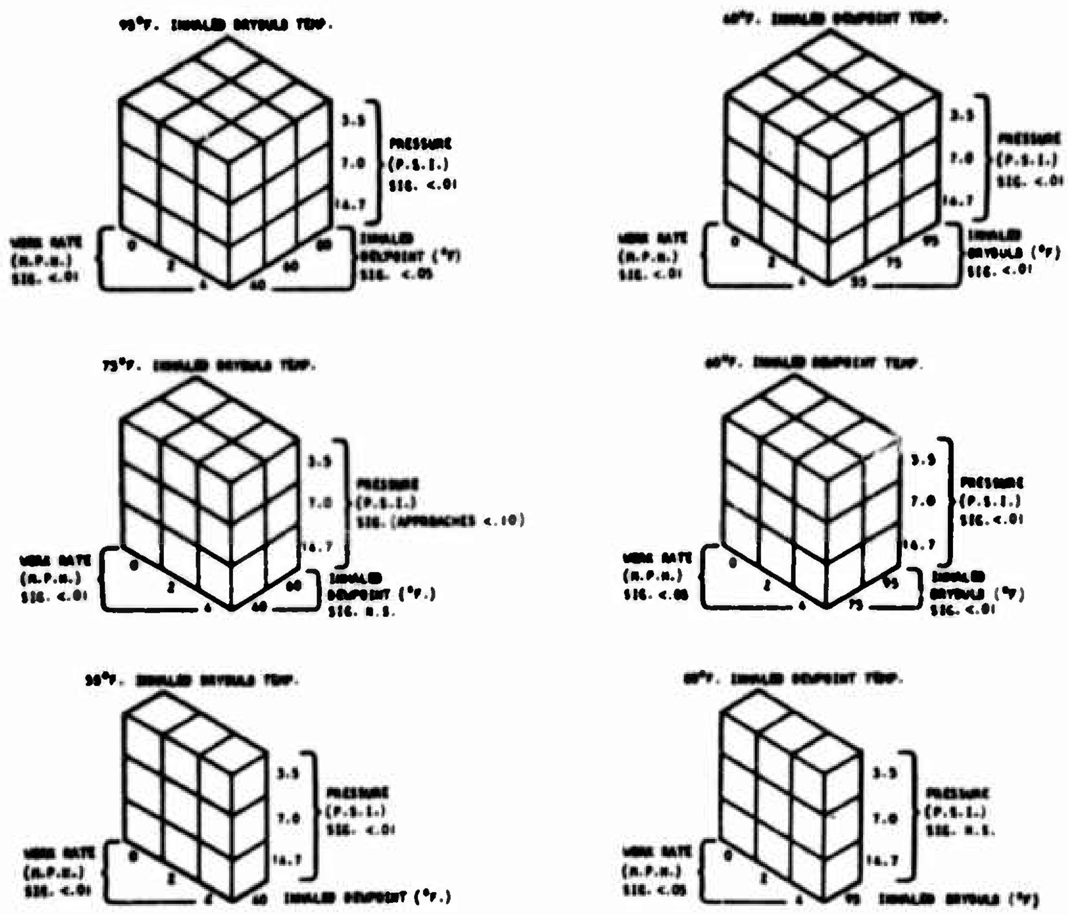


FIGURE 58

Analysis of variance matrices; dependent variable rectal temperature, °F.

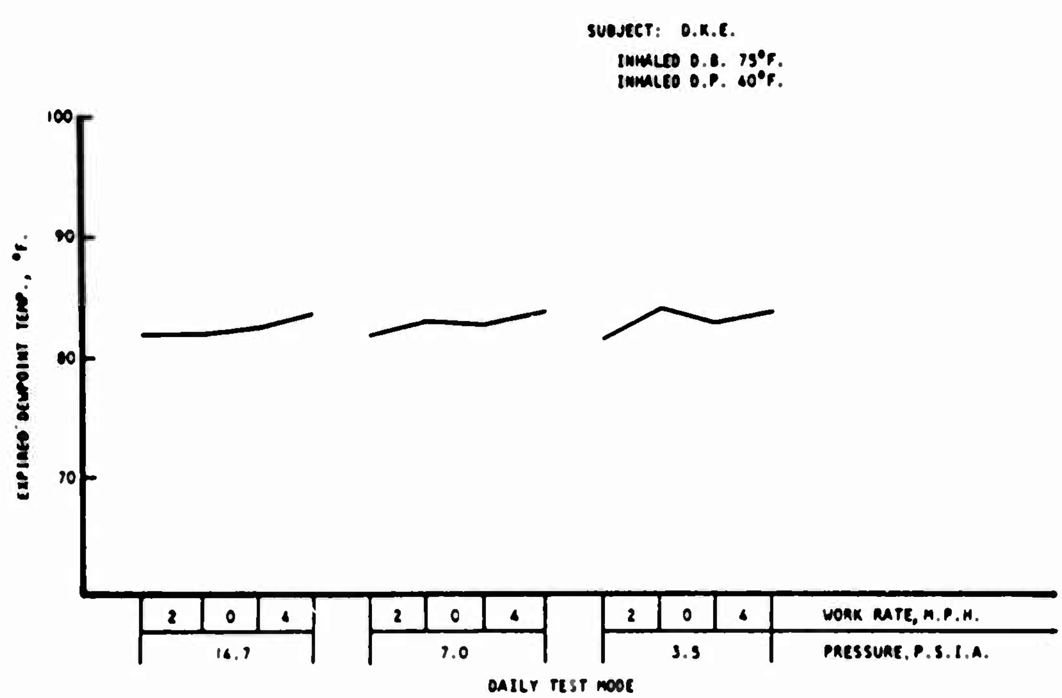


FIGURE 59

Typical daily observation, expired dewpoint temperature.

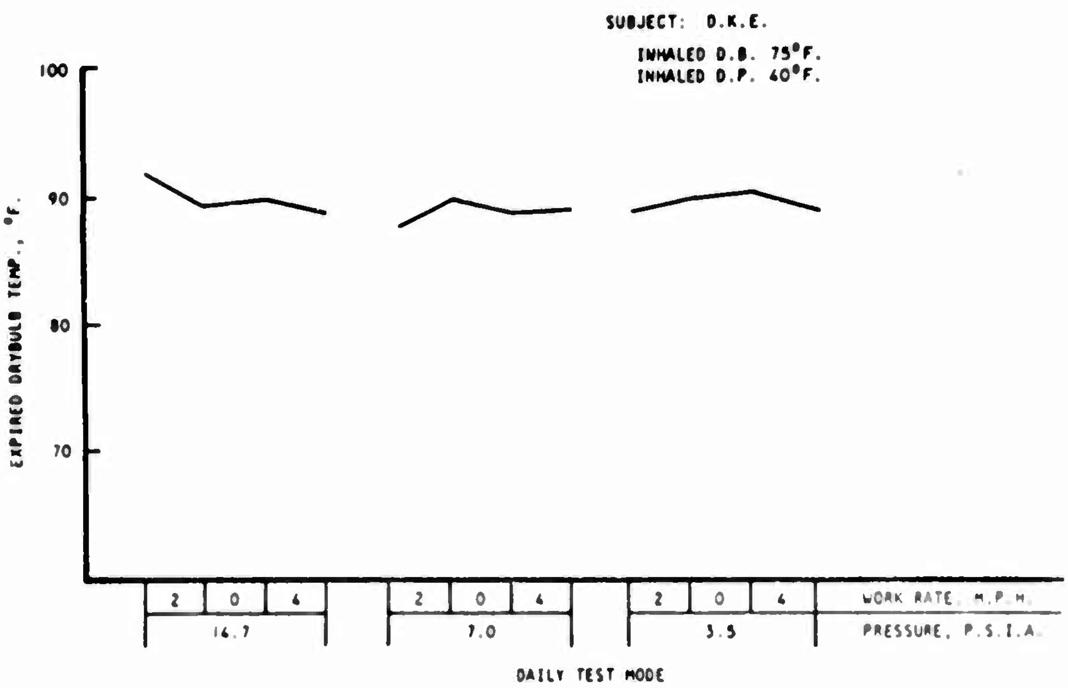


FIGURE 60

Typical daily observation, expired drybulb temperature.

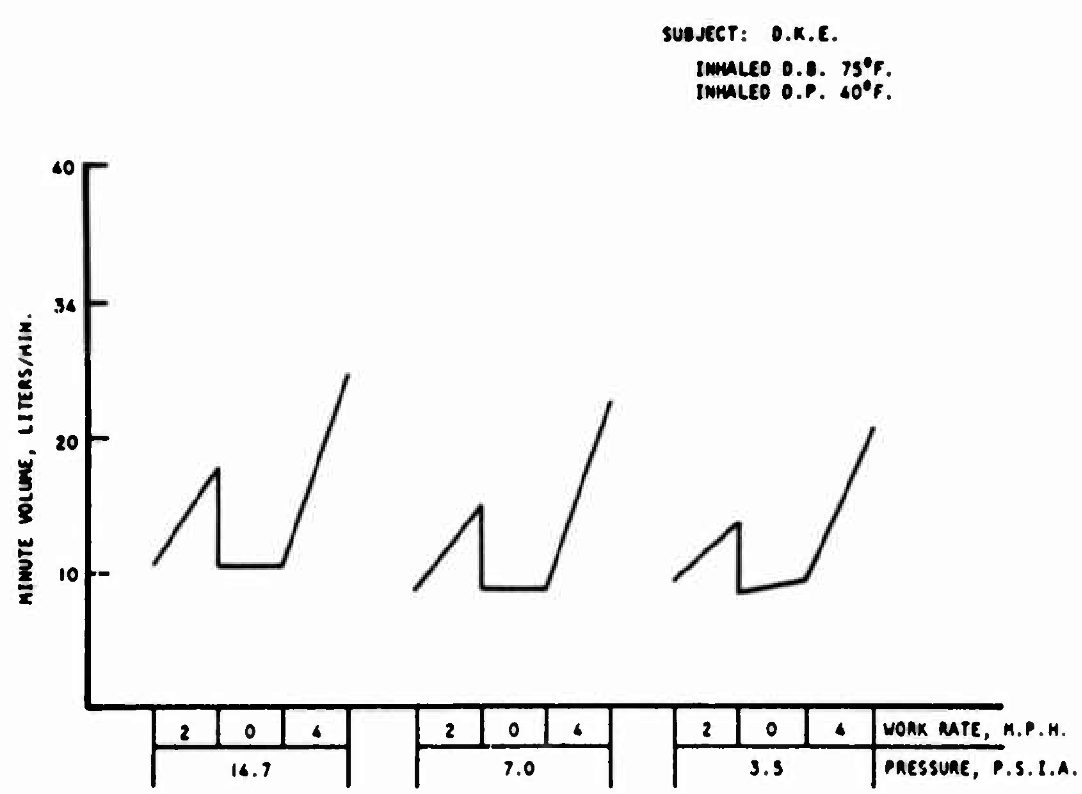


FIGURE 61

Typical daily observation, minute volume, liters per minute.

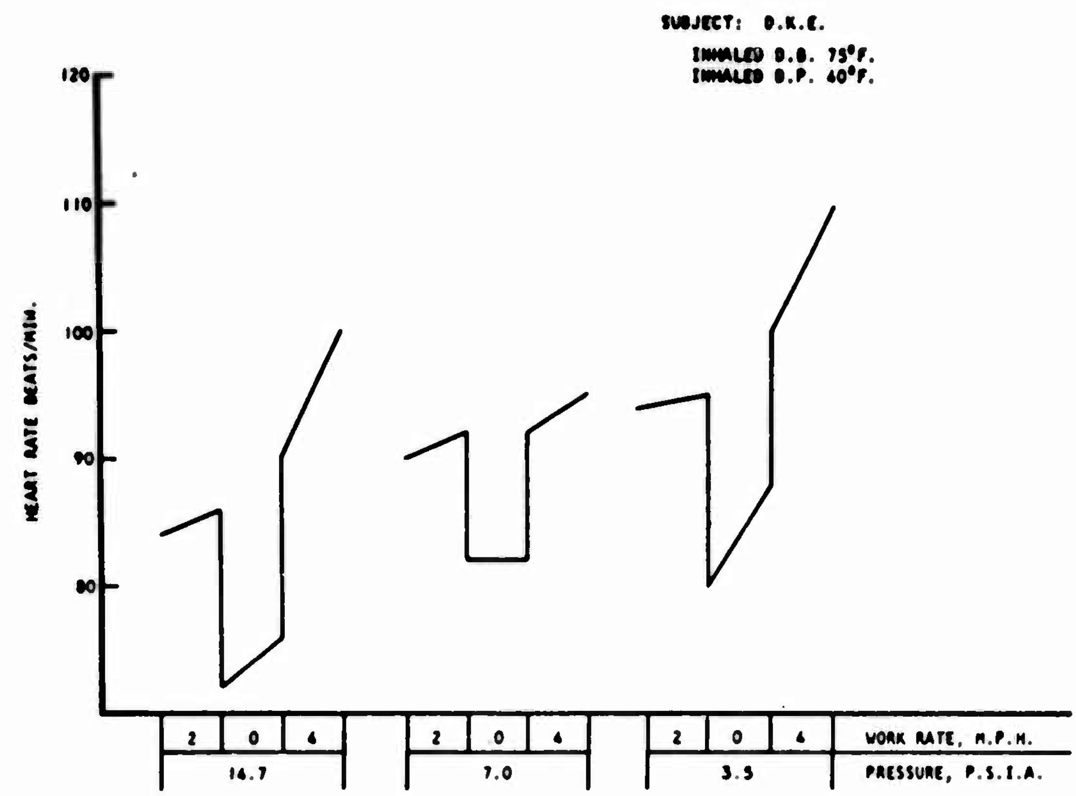


FIGURE 62

Typical daily observation, heart rate, beats per minute.

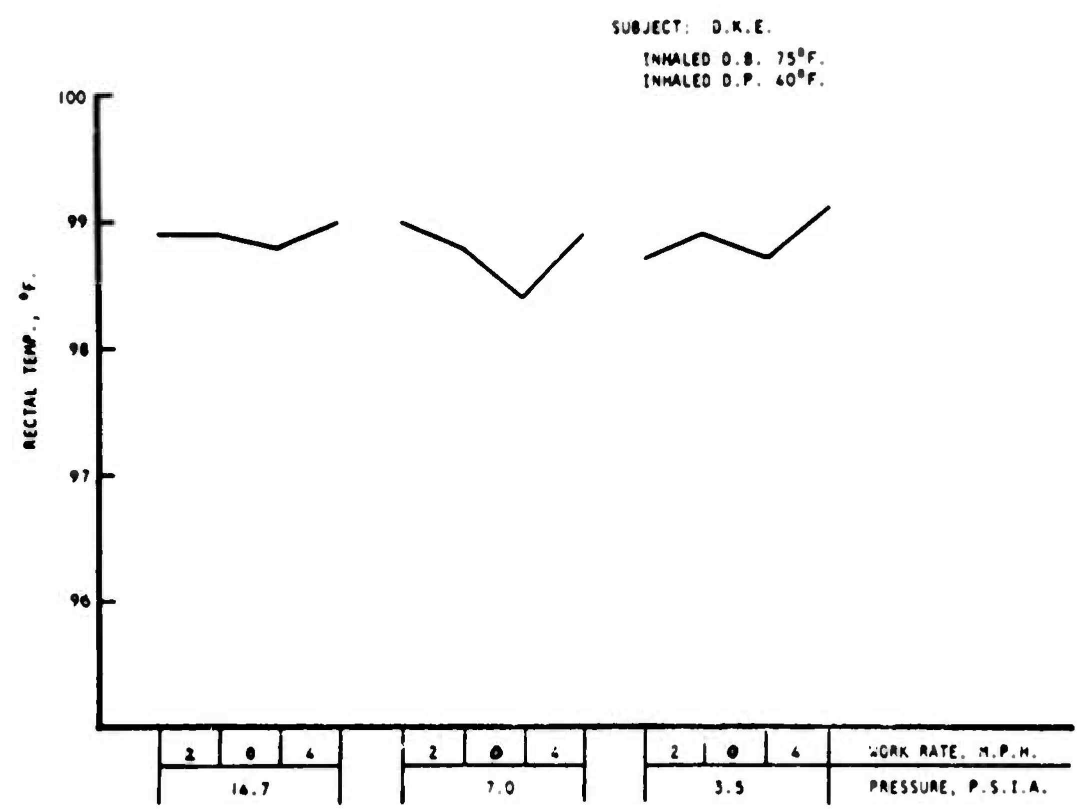


FIGURE 63

Typical daily observation, rectal temperature, °F.

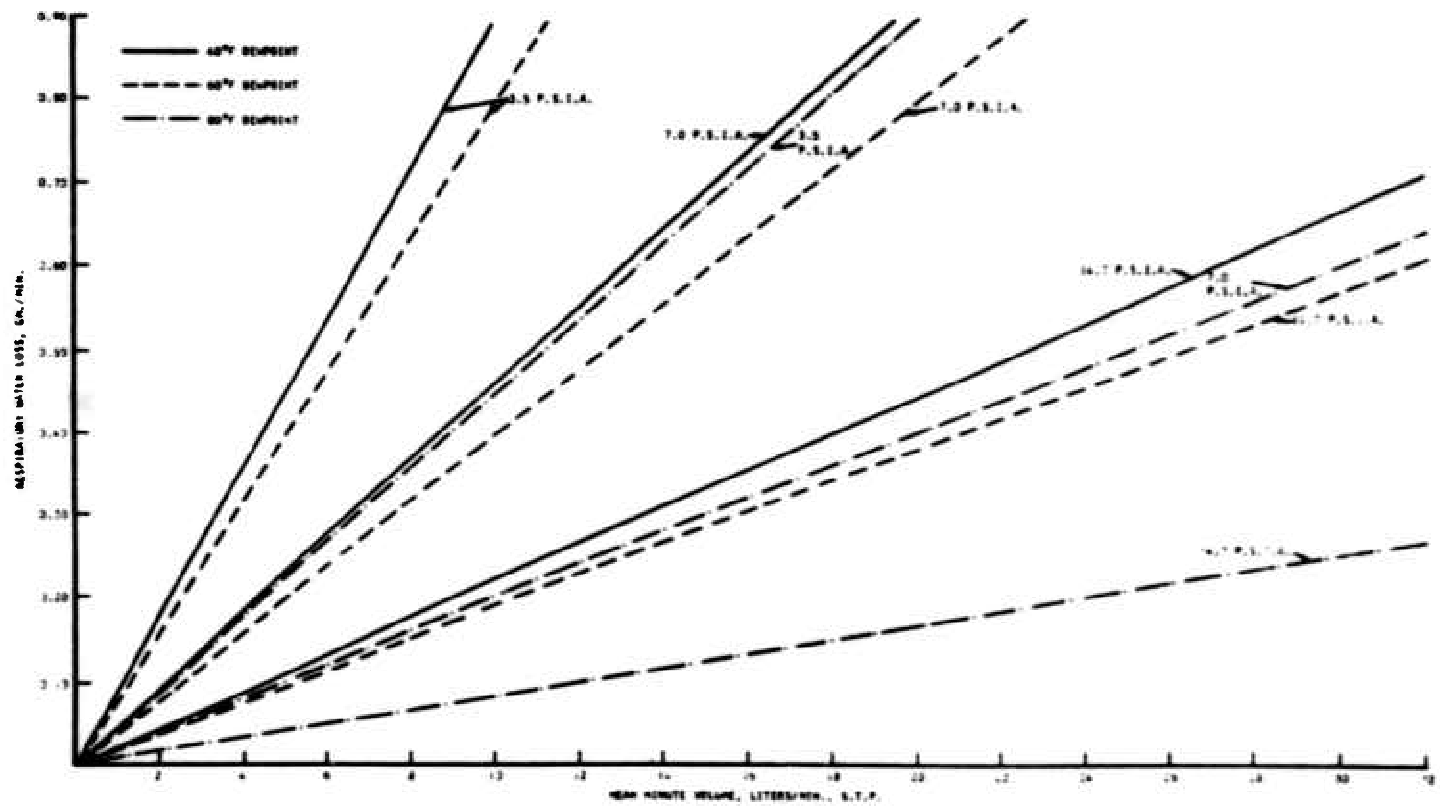


FIGURE 64

Respiratory water loss, grams per minute, as a function of minute volume, liters per minute at STP, for all work rates and drybulb temperatures.

Marshall and Specht noted an increased water vapor pressure at altitude, which could lead to the assumption that respiratory loss would have increased had the minute volume not decreased considerably. Results of this program, however, indicate no significant increase or decrease of the water loss (grams per liter) with increasing altitude. Exhaled dewpoint, however, did vary significantly with inhaled dewpoint temperature.

Marshall and Specht also observed a significant decrease in exhaled dewpoint temperature with altitude; data obtained in this program showed a significant increase in exhaled dewpoint only with the high-humidity inhaled gas at 80° F. dewpoint. In the work reported here, another variable which correlated with expired dewpoint was drybulb temperature, a factor not varied by Marshall and Specht.

Although McCutchan and Taylor (19) presented data points for conditions beyond the range of our experiments, they also observed that the expired dewpoint temperature varies directly with inhaled drybulb temperature. The work reported here further corroborates the results of these two groups of authors. In addition, our data show that exhaled drybulb temperature did not vary significantly with pressure.

One of the major conclusions of Marshall and Specht is that the rate of respiratory water loss is directly related to pulmonary ventilation. Our results agree with this, as is indicated by the high correlation between minute volume and respiratory water loss in grams per minute. In both cases, it is apparent that the reduced pulmonary ventilation at decreased pressures is a basic factor in the decreased water loss.

Burch (18), Seeley (16), Christie and Loomis (17) and McCutchan and Taylor (19) all report that the exhaled gas is unsaturated. Both Seeley and McCutchan and Taylor report ranges of 80 to 90% saturation.

Our data corroborate these findings but extend the range to 70 to 90% depending on the inhaled conditions; the lowest exhaled humidities (70%) were observed at the 95° F. drybulb, 40° F. dewpoint condition.

Independent corroboration of our general observations is found in the changes observed in rectal temperature. These changes correspond to all test parameters, including parameters that affected only respiratory heat transfer. For example, rectal temperature increased with increases in both inhaled drybulb and dewpoint temperatures.

VI. CONCLUSIONS

The results of this experiment indicate that when subjects are breathing pure oxygen by mouth:

1. Respiratory water loss, measured as mass transferred per unit time, decreases with reduced pressure.

2. Respiratory water loss is a positive monotonic function of work rate and the temperature of the inhaled gas, and a negative monotonic function of the dewpoint of the inhaled gas.

3. Minute volume (ATP) for a given exercise rate decreases with reduction in pressure, and this decrease, for a given combination of inhaled dewpoint and drybulb temperature, accounts for the accompanying reduction in respiratory water loss.

4. ΔH_2O respired = K (minute volume ATP)

K = a constant determined by the drybulb and dewpoint temperature of the inspired gas and

ΔH_2O respired = C (minute volume STP)

C = a constant determined by the dewpoint and pressure of the inhaled gas.

5. Exhaled dewpoint temperature is primarily and directly dependent on inhaled dewpoint; elevation of the inhaled drybulb temperature, however, also elevates the dewpoint temperature of exhaled gas.

6. Exhaled drybulb temperature varies directly with both inhaled drybulb and dewpoint temperatures of inhaled gas and inversely with work rate.

7. The expired gas never became saturated nor did it reach body temperature.

REFERENCES

1. Newburgh, L. H., and M. W. Johnston. The insensible loss of water. Physiol. Rev. 22:1 (1942).

2. Foá, C. Critique experimentale des hypothèses émises pour expliquer l'hyperglobulie de la haute montagne. Arch. Ital. Biol. 41:101 (1904).

3. Guillemard, M. H., and R. Moog. Étude expérimentale sur les variations des échanges respiratoires et de la déshydratation de l'organisme sous l'action du climat de haute montagne. J. Physiol. Path. Gén. 12:869 (1910).

4. Galeotti, G. Ueber die Ausscheidung des Wassers bei der Atmung. Biochem. Z. 46:173 (1912).

5. Galeotti, G. Wassergehalt und Temperatur der ausgeatmeten Luft. Pflueger Arch. Ges. Physiol. 160:27 (1915).

6. Benedict, F. G., and C. G. Benedict. Perspiration insensibilis: Ihr Wesen und ihre Ursachen. Biochem. Z. 186:278 (1927).

7. Jores, A. Perspiratio insensibilis. Z. Ges. Exp. Med. 71:170 (1930).

8. Adachi, J., and S. Ito. Insensible perspiration through the skin and the respiratory passages and compensating changes in cutaneous perspiration. J. Orient. Med. 21:103 (1934).

9. Burch, G. E., and T. Winsor. The relation of total insensible loss of weight to water loss from the skin and lungs of human subjects in a subtropical climate. Amer. J. Med. Sci. 209:226 (1945).

10. Thauer, R., W. Kaufmann, and G. Zoellner. Der insensible Gewichtsverlust als Funktion der Umweltbedingungen. Pflueger Arch. Ges. Physiol. 261:183 (1955).

11. Thauer, R., and G. Zoellner. Der insensible Gewichtsverlust als Funktion der Umweltbedingungen. Seine Abhaengigkeit von dem Wasserdampfdruck der Luft im indifferenten Temperaturbereich. Pflueger Arch. Ges. Physiol. 258:58 (1953).

12. Thauer, R., G. Zoellner, and W. Kaufmann. Der insensible Gewichtsverlust als Funktion der Umweltbedingungen. Der Anteil von Atmung und Haut an der Gesamtperspiratio. Pflueger Arch. Ges. Physiol. 260:1 (1954).

13. Pfeiderer, H., and L. Less. Die Klimatischen Anspruehe an die Atemwege des menschlichen Koerpers. Bioklimat. Beibl. 2:1 (1935).

14. Corlette, C. E. On the calculation of heat and moisture dissipated from the body by respiration. Med. J. Aust. 2:198 (1942).

15. Buettner, K. Physikalische Bioklimatology, Probleme und Methoden. Leipzig: Akademische Vellagsgesellschaft MBH, 1938.

16. Seeley, L. E. Study of changes in the temperature and water vapor content of respired air in the nasal cavity. Trans. Amer. Soc. Heat Vent. Engr. 46:259 (1940).

17. Christie, R. V., and A. L. Loomis. The pressure of aqueous vapour in the alveolar air. J. Physiol. (London) 77:35 (1932).

18. Burch, G. E. Rate of water and heat loss from the respiratory tract of normal subjects in a subtropical climate. Arch. Intern. Med. (Chicago) 76:315 (1945).

19. McCutchan, J. W., and C. L. Taylor. Respiratory heat exchange with varying temperature and humidity of inspired air. J. Appl. Physiol. 4:121 (1951).

20. Loewy, A., and H. Gerhartz. Ueber die Temperatur der Exspirationsluft und der Lungenluft. Pflueger Arch. Ges. Physiol. 155:231 (1914).

21. Marshall, L. H., and H. Specht. Respiratory water vapor at simulated altitude. Amer. J. Physiol. 156:299 (1949).

22. Benzinger, T. H. On physical heat regulation and the sense of temperature in man. Proc. Nat. Acad. Sci. USA 45:645 (1959).

23. Comroe, J. H., R. E. Forster, A. B. Dubois, W. A. Briscoe, and E. Carlson. The lung. Chicago: Year Book Publishers, 1962.

24. Handbook of respiration, National Academy of Sciences. Philadelphia: W. B. Saunders Co., 1958.

25. Rossier, P. H., A. A. Buhlman, and K. Wiesinger. Respiration. St. Louis: C. V. Mosby Co., 1960.

26. Ulvedahl, F., T. E. Morgan, R. G. Cutter, and B. E. Welch. Respiratory function studies during prolonged exposure to simulated altitude without hypoxia. SAM-TDR-63-31, May 1963.

27. Jaeger, M. D., and A. B. Otis. Effects of the compressibility of alveolar gas on the dynamics and work of breathing. SAM-TDR-63-71, Oct. 1963.

28. Fenn, W. O. The pressure-volume diagram of the breathing mechanism. *In* Boothby, W. M. (ed.). Handbook of respiratory physiology, pp. 19-27. Randolph Field, Texas: USAF School of Aviation Medicine, 1954.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Department of Life Sciences AiResearch Manufacturing Company Los Angeles, California	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

REDUCED BAROMETRIC PRESSURE AND RESPIRATORY WATER LOSS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

1 Apr. - 31 Oct. 1964

5. AUTHOR(S) (Last name, first name, initial)

Wortz, Edward C.
Diaz, Robert A.
Green, Frederick H.
Sanborn, Warren G.
Edwards, David K., III
Prescott, Edmund J.
Scherer, Gilbert R.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
Feb. 1966	73	28

8a. CONTRACT OR GRANT NO. AF 41(609)-2389	9a. ORIGINATOR'S REPORT NUMBER(S) SAM-TR-66-4
b. PROJECT NO.	
c. Task No. 793002	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d	

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas

13. ABSTRACT

Respiratory water loss was investigated with a group of normal subjects breathing oxygen orally. Data were collected from all subjects under three absolute pressures (3.5, 7.0, and 14.7 p.s.i.), three work rates on a treadmill (0, 2, and 4 m.p.h.), three humidities of the inspired oxygen (40° F., 60° F., and 80° F. dewpoint), and three drybulb temperatures of the inspired oxygen (95° F., 75° F., and 55° F.). The data were analyzed statistically.

All of these variables affected respiratory water loss in varying degrees. Reduced pressure diminished respiratory water loss, apparently because of a corresponding decrease in minute volume observed at lower pressures. Increased work rates elevated pulmonary ventilation and thus increased respiratory water loss. Increasing humidity decreased water loss, while increasing drybulb temperature produced greater water loss. Expired gas temperatures approached body temperature only at elevated inspired temperature; the expired gas volume was never saturated.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Physiology						
Respiratory water loss						
Water loss, insensible						
Respiratory physiology						
Barometric pressure, reduced						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification