ABSTRACT

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A total of 27 Ss from the University of Wisconsin-La Crosse, ages 19-34 yrs, volunteered to participate in the validation study of the Q-Plex I Cardiopulmonary Exercise System developed by the Quinton Instrument Company. Each S performed a constant speed, grade incremented treadmill test to volitional exhaustion. Simultaneous measurements of expired air were performed with the Q-Plex and a meteorological balloon gas collection system to determine the validity of the Q-Plex. Respiratory and metabolic assessments were made during at least 3 different levels of exercise; low steady state, medium steady state, and at maximal exertion. A total of 93 gas samples were collected and analyzed by the 2 methods. The means for FeO_2 and $FeCO_2$ were significantly ($p<0.05$) different. However, the absolute mean differences were only 0.5% for O_2 and 0.3% for CO_2 which are within the accuracy of the reported error for the analyzers. These results indicated that the Q-Plex gas analyzers are as accurate as the micro-Scholander technique. Correlation coefficients between the 2 systems were .9735 for FeO_2 and .9729 for $FeCO_2$. After all the validation data were collected a final comparison was made between a series of volumes obtained with the Parkinson-Cowan

meter and the Tissot spirometer. These results indicated there was a much larger discrepancy in volumes obtained between these methods than those initially reported. These differences were of sufficient magnitude to question the accuracy of using this meter to validate the volumes obtained with the Q-Plex. Since it was impossible to determine the cause of this error, or at what point in the study it occurred, the VE volumes of the Q-Plex could not be legitimately validated using the Parkinson-Cowan meter. Unfortunately, since the accuracy of measuring VO_2 and VCO_2 is dependent upon VE volumes, neither of these volumes could be compared. Within the limitations of the present study, it was concluded that the gas analyzers in the Q-Plex demonstrate accuracy comparable to that of the micro-Scholander technique.

A VALIDATION STUDY OF THE
Q-PLEX I CARDIOPULMONARY EXERCISE SYSTEM

A THESIS PRESENTED

TO

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TABLE OF CONTENTS

PAGE

CHAPTER PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

LIST OF APPENDICES

APPENDICES PAGE

CHAPTER I

INTRODUCTION

With advances in today's technology, especially in the form of new equipment, the work environment has become significantly more efficient. Many laborious and time consuming tasks are gradually being replaced by sophisticated machines capable of performing the same analysis in a fraction of the time. One such task which has been made easier and faster to perform as a result of these advances is the assessment of metabolic and respiratory functions during exercise. The classic techniques used to assess these functions, as described by Consolazio, Johnson, and Pecora (1963), use Douglas bags, large spirometers or gas meters, and chemical gas analyzers. These methods require large amounts of time just for simple data acquisition not including the additional time necessary for analysis of the data. As technology advanced, several automated systems were developed which employed the use of rapidly responding electronic gas analyzers, electronically activated gas volume sensing devices, and relatively large dedicated computers (Beaver, Wasserman, & Whipp, 1973; Wilmore & Costill, 1973; Wilmore & Haskell, 1971).

Using computers for data acquisition during exercise testing has increased accuracy, reliability, and objectivity. In addition, computer usage has reduced time to complete the test and requires fewer technicians to assist in the testing procedure. Unfortunately, these systems use rather large, expensive computers and were, for the most part, not easily portable for use in field testing (Wilmore, Davis, & Norton, 1976). However, a system described by Norton, Mashikian, Wilmore, and Rader (1976), the Beckman Metabolic Measurement Cart, met the demands for on-line analysis during exercise testing, simple data collection, accuracy, and mobility. Therefore, it was practical for mass testing. This was used in the Human Performance Laboratory at the University of Wisconsin-La Crosse for approximately 13 years.

As computer technology continued to progress, equipment using these advanced computers became more sensitive, specific, and user friendly. The Q-Plex I Cardiopulmonary Exercise System (Q-Plex) (developed by Quinton Instrument Company) has been developed to provide respiratory and metabolic assessment during exercise performance. The Q-Plex determines, calculates, displays, and prints numerous parameters in "real time" including minute ventilation, respiratory exchange ratio, oxygen consumption, and carbon dioxide production thus allowing for immediate diagnosis and feedback to the subject. Furthermore it stores gas exchange data for each breath.

Quinton claims to use an innovative method that raises the standard in pulmonary exercise measurements. According to Quinton, by having keyboard control of the gas sampling pathway, the tester can switch from a traditional mixing chamber approach to end-tidal readings from the breathing valve (Quinton, 1987). This methodology provides a smooth, easily interpreted graphic display of mixing chamber data and allows the tester to have end-tidal measurements for anaerobic threshold determination and the physiological dead space to tidal volume ratio (Vd/Vt). The Q-Plex gives single breath or timed-interval data acquisition and continuous analysis throughout the test. The data can be displayed according to number of breaths or a certain time interval. If a subject disconnects or stops during the study, the "Pause and Resume" feature automatically completes the data analyses and protects the validity of the data.

These claims made by Quinton appear to make the technology of the Q-Plex superior to other metabolic measurement systems on today's market at an equivalent cost. However, one can not purchase a $30,000.00 plus instrument based on claims made by the designers of the system. For this reason, the following study was developed to determine the validity of the Q-Plex.

Need for the Study

Prior to any commitment to purchase a computerized metabolic measurement system, the La Crosse Human Performance Laboratory personnel must establish the validity of the system before it can be put to clinical use.

Statement of the Problem

The purpose of this study was to determine the validity of the Q-Plex I Cardiopulmonary Exercise System developed by the Quinton Instrument Company. The study was based on comparing the Q-Plex data to data from a meteorological balloon gas collection method with gas fractions analyzed by the micro-Scholander method (Scholander, 1947). These procedures were used to analyze subjects' ventilations, oxygen uptakes, and carbon dioxide productions.

Null Hypothesis

The major hypothesis of this study was: there will be no significant difference between ventilation volumes, fractional concentrations of expired oxygen, fractional concentrations of expired carbon dioxide, volumes of oxygen consumed $ml \cdot kg^{-1} \cdot min^{-1}$, volumes of carbon dioxide produced in liters per minute, and respiratory exchange ratios between the Q-Plex and the standard meteorological balloon gas collection method obtained at various levels of ventilation.

Assumptions

The following assumptions were relative to this study:

1. The meteorological balloon gas collection method and the micro-Scholander gas analysis procedure are valid and reliable reference techniques.

2. The dry Parkinson-Cowan meter used for measuring volume is a valid and reliable reference device.[1]

3. All testing procedures were administrated consistently.

4. The subjects obtained a steady state during all gas collection periods.

5. The gas samples used for analysis were representative of one full minute of expired gas.

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[1] After completion of this study the specific Parkinson-Cowan meter used was found to be inaccurate.

Limitations

The following limitations were relative to this study:

1. Subjects were male college age volunteers available from the University of Wisconsin-La Crosse who were previously tested and had a VO_2max level of 55 $ml \cdot kg^{-1} . min^{-1}$ or higher.

2. Only ventilation volumes, fractional concentrations of expired oxygen, the fractional concentrations of expired carbon dioxide, volumes of oxygen consumed in liters per minute, volumes of carbon dioxide produced in liters per minute, and respiratory exchange ratios were actually compared by the two methods.

3. The validity of other measurements performed by the Q-Plex was beyond the scope of this study.

Definition of Terms

Selected terms as interpreted and applied in the content of this study are as follows:

ATPS - Ambient temperature and pressure saturated with water vapor.

Bailey Bottle - A compact, hand held gas transfer bottle for use with the micro-Scholander method of gas analyzing.

BTPS - Body temperature (37°C), ambient pressure, and 100% water saturation. Used for all gas measurements dealing in lung volume.

Carbon Dioxide Production (VCO_2) - The volume of carbon dioxide produced by the body per unit of time ($liters \cdot min^{-1}$ at STPD).

Dead Space (mechanical) - The area common to both inspiration and expiration, such as the breathing valve.

Dead Space (physiological) - The area of the conducting airways which does not take part in gas exchange.

Differential Pressure Pneumotachometer - The volume measuring device used by the Q-Plex.

$FeCO_2$ - The fractional concentration (by volume) of expired carbon dioxide in a gas.

FeO_2 - The fractional concentration (by volume) of expired oxygen in a gas.

Meteorological Balloon - A natural rubber moisture-proof polyethylene sealed bag used for collection of expired gas.

Minute Ventilation Volume - The amount of gas expired in one minute.

Oxygen Uptake (VO_2) - The volume of oxygen consumed by the body per unit of time (liters$\cdot$min^{-1} at STPD or ml$\cdot$kg$^{-1}\cdot$min^{-1}).

Parkinson-Cowan Dry Gas Meter - The volume measuring device used in the meteorological balloon reference method.

Q-Plex I Cardiopulmonary Exercise System (Q-Plex) - A system developed by the Quinton Instrument Company (Seattle, WA) designed to provide respiratory and metabolic assessment during exercise.

Respiratory Exchange Ratio (RER) - The ratio of carbon dioxide production to oxygen consumption over the same period of time.

Meteorological Balloon Reference Method - The method designed to measure minute ventilation volume, fractions of oxygen and carbon dioxide in the expired air, the volume of oxygen used by the body and the volume of carbon dioxide produced by the body, and the respiratory exchange ratio after the gas has passed through the Q-Plex.

STPD - Standard temperature (0°C) and pressure (760 mmHg) as a dry gas. Used for expressing the volume of gases exchanged in metabolic measurements.

Tissot Spirometer - A calibrated 120 liter cylinder sealed from the outside air by using a water seal in a second cylinder. It is used as a standard to measure gas volumes.

Vd/Vt - The ratio of physiological dead space to tidal volume.

VE - The total volume of gas expired in one minute (liters$\cdot$min^{-1} at BTPS).

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

With the advancements made in computer technology, the assessment of metabolic and respiratory function during exercise has become easier and faster. One of the most frequently measured metabolic functions on human subjects is oxygen consumption (VO_2). Oxygen consumption is defined as the volume of oxygen consumed by the body per unit of time (Astrand & Rodahl, 1977; Brooks & Fahey, 1984; Knuttgen, 1969; McConnell, 1988; Wilmore & Costill, 1988). Not only are researchers interested in the amount of oxygen the body uses at rest, but they are also interested in knowing the maximal amount of oxygen that can be delivered and utilized by the working muscles when exercising to exhaustion. This is known as maximal oxygen consumption (VO_2max). Because VO_2max has been regarded as the best measure of cardiorespiratory endurance and aerobic fitness it is frequently measured (Bonen, Heyward, Cureton, Boileau, & Massey, 1979; Egger & Finch, 1988; Francis & Cuipepper, 1988; Glassford, Baycroft, Sedgewick, Macnab, 1965; Hermiston & Faulkner, 1971; Johnson, Oliver, & Terry, 1979; Kline et al., 1987; McArdle, Katch, & Katch, 1986; Ramsbottom, Brewer, & Williams, 1988; Rowell, Taylor, & Wang, 1964; Steinacker, Marx, Marx, & Lormes, 1986).

To determine VO_2 one must be able to measure minute ventilation (VE) at a known temperature, pressure, and relative humidity (ATPS), fractional concentration of expired oxygen (FeO_2), fractional concentration of expired carbon dioxide ($FeCO_2$), barometric pressure (P_B), temperature (T), and time. Since VE is initially measured at ATPS during open-circuit spirometry, it must be corrected to standard temperature (0^oC) and pressure (760 mmHg) of a dry gas (STPD) so it is possible to evaluate and compare the volumes of expired air measured under different environmental conditions. From these measurements VO_2 corrected to STPD can be determined as well as carbon dioxide production (VCO_2), and respiratory exchange ratio (RER). Conventionally, lung volumes such as VE are converted from ATPS to body temperature, ambient pressure, and 100% saturated with water vapor (BTPS) (see Appendix A for calculations).

The instruments used to measure P_B, T, and time have not changed with advanced technology. These instruments, mercury barometers, thermometers, and stop watches, tend to be very accurate, reliable, and easy to use. However, instruments used in the measurement of VE, FeO_2, and $FeCO_2$ have changed considerably since the early 1900's. Not only have these instruments become computerized allowing for faster data analysis, increased accuracy, reliability, and objectivity but they have also become integrated into one system making them more convenient for mass testing and user friendly.

Such is the case with the Q-Plex I Cardiopulmonary Respiratory System. In this Chapter, indirect calorimetry and the classical technique used for comparison in the validation of such metabolic measurement systems are described. Also, a historical approach is used to trace the advances made in systems used to measure oxygen consumption.

Indirect Calorimetry

Throughout the years, the measurement of VO_2 has become an integral component of laboratories involved in the evaluation and measurement of human performance. During rest and exercise the body's metabolic processes utilize oxygen and produce carbon dioxide. The amount of energy expended during activity is, therefore, directly related to the exchange of these two respiratory gases (Consolazio et al., 1963). As a person exercises, these gases can be collected from the expired air and measured. This procedure is commonly known as "indirect calorimetry" and can be conducted using several different methods. One method, termed "closed-circuit", does not involve the equipment used in this study and is not commonly used, and therefore will not be discussed. A second method, termed "open-circuit" involves the subject inspiring atmospheric or "room" air and expiring into a container used to mix the expired gas for continuous analysis and, if necessary, storage. The VE is determined one of two ways: either the expired air is measured directly or the inspired gas is measured and then converted to expired by the Haldane transformation (Wilmore & Costill, 1973). Upon completion of the exercise session, expiratory gas samples are removed from the container for analysis. For many years the most common technique used for "open-circuit calorimetry" has employed the Douglas bag technique (Balchum, Hartman, Slonim, Dressler, & Ravin, 1953; Haldane & Priestly, 1935; Perkins, 1954; Shephard, 1955).

Douglas Bag Technique

The Douglas bag technique for the collection and measurement of expired air is considered by many to be the standard method of measurement for comparison purposes in the validation of metabolic measurement systems measuring VE, FeO_2, and $FeCO_2$ (Beaver et al., 1973; Consolazio et al., 1963; Norton, 1982; Norton et al., 1976; Wilmore & Costill, 1974; Wilmore et al., 1976). This technique uses a nonrebreathing valve and a Douglas bag or a similar device (i.e., meteorological balloons) for collection of expired gas, large spirometers or gas meters for the measurement of VE, and chemical or electronic gas analyzers for the measurement of FeO_2 and $FeCO_2$. Although reliable, this method is very time consuming, several technicians are needed during the test, and a skilled technician is needed to use the chemical gas analyzers.

Collection and Mixture of Expired Gas

During the Douglas bag technique a nonrebreathing valve is used to collect the total expired gas without contamination from the inspired gas or room air. The nonrebreathing valve is designed to allow air to be drawn into the lungs from the inspired air port. During inspiration, the inspired air port opens and the expired air port closes. During expiration, the inspired air port closes and the expired air port opens so that all of the expired air from the subject goes out the expired air port of the nonrebreathing valve. The pressure difference within the valve opens or closes the ports. The inspired port of the nonrebreathing valve is connected to room air while the expired side is connected to a Douglas bag for the collection and mixture of the total expired gas. A nose clip and rubber mouthpiece are also used to insure that the total air flow goes through the valve.

Measurement of Expired Gas Volume

Several methods of measuring gas volume have been developed and commonly used. Two general categories are: (1) those which collect the expired air in containers for subsequent analysis, and (2) those which measure and indicate volume as the air is expired. The two most commonly used devices for measuring gas volume (after the samples have been collected) are the Tissot spirometer and gas meters such as the Parkinson-Cowan type. Both of these devices can also be used to measure the expired volume during the measurement period but require considerably more agility on the part of the experimenter. The Parkinson-Cowan dry gas meters used to measure expired volume as reported by Consolazio et al. (1963) are found to be accurate to about 1% when they are calibrated against a large Tissot spirometer. Two additional spirometers, the Wright and the Drager, have also been used to measure expired volume. The Wright spirometer, however, is extremely fragile and can be damaged by fast flow rates (Jones, Campbell, Edwards, & Robertson, 1975). The Drager spirometer, on the other hand, has considerable resistance to air flow (Norton, 1976).

Of all the various parameters which must be measured to determine metabolic variables, those which offer the greatest difficulty to accurately measure are expired gas volumes and flow measurements (Norton, 1976). The dials and readout meters of some volume measuring devices may suggest that they indicate an absolute volume. Nonetheless, these are usually different from device to device so that a calibration factor is required for each separate instrument (Norton, 1976).

Analysis of Mixed Expired Gas

For many years the most widely used method for the measurement of gas fractions during the Douglas bag technique was the Haldane procedure. This method and its many modifications utilize the simple principle of the measurement of the gas volume in a calibrated burette and the subsequent absorption of the oxygen and carbon dioxide chemically (Haldane & Priestley, 1935). During this procedure the carbon dioxide in a known volume of expired air is absorbed with potassium hydroxide, and the oxygen is absorbed with a strong pyrogallic acid or sodium anthraquinone B-sulfonate solution. The remainder of gas is considered to be nitrogen. However, most of the conventional Haldanes can analyze only up to 30 percent of either oxygen or carbon dioxide in a given sample, making it very difficult to measure expired air samples with high concentrations of oxygen. As a result, the technician had to resort to the Van Slyke procedure for measuring high concentrations of oxygen in expired air samples (Consolazio et al. 1963). This procedure is also very time consuming and requires a significant amount of training.

A more recent piece of equipment for measuring expired gas fractions using the Douglas bag technique was introduced by Scholander. In 1947 Scholander, using the same basic principle as Haldane, proposed a drastic change in the apparatus for measuring expired air by using an accurately calibrated micrometer as a measuring device. The principle involved in this technique is fairly detailed and complex, but is described in more general terms by Scholander (1947) in the following manner:

> A gas sample is introduced into a reaction chamber connected to a micrometer burette and is balanced by means of an indicator drop in a capillary against a compensating chamber. Absorbing fluids for carbon dioxide and oxygen can be tilted into the reaction chamber without causing any change in the total content of the system. During absorption of gas, mercury is delivered into the reaction chamber from the micrometer burette so as to maintain the balance of the gas against the compensating chamber. Volumes are read in terms of micrometer divisions. The rinsing fluid and absorbents are accurately adjusted to have the same vapor tension (p. 235).

This analyzer is able to determine the fraction of oxygen and carbon dioxide in 0.5 cc or less of gas with an accuracy of plus or minus 0.015 volume percent. This method is superior to the Haldane procedure in many ways, especially since one could now analyze samples that contain from 0 to 99% absorbable gases. Although detailed, the entire procedure requires only 6 to 8 minutes to complete.

Development of Automated Systems Used to Measure VO_2

The first breakthrough in simplification of the data acquisition aspect in the assessment of metabolic and respiratory function on human subjects came in 1946 with the development of a rapidly responding oxygen analyzer (Pauling, Wood, & Sturdivant, 1946). Subsequently, it was shown in the 1950's that carbon dioxide in expired air could be analyzed fairly rapidly using an infrared gas analyzer (Brown, 1952; Collier, Affeldt, & Farr, 1955; Du Bois, Fowler, Soffer, & Fenn, 1952; Saxton, 1953). These analyzers, which made the measurement of respiratory gases in expired air much simpler and faster than the Haldane or Scholander technique, revolutionized the field of energy metabolism by eliminating the need for the traditional chemical gas analyzers in the exercise testing procedure.

With the development of rapidly responding electronic gas analyzers and electronic volume measuring devices, combined with small dedicated computers, complete systems for assessing metabolic and respiratory function during exercise have been developed (Johnson et al., 1967, Kannagi et al., 1983; Norton, 1982; Versteeg & Kippersluis; Wilmore & Costill, 1973; Wilmore & Costill, 1974; Wilmore et al., 1976; Wilmore & Haskell, 1972). However, the reliability and validation data for most of these systems are not easily found in the literature. Usually, only the calibration procedures used are reported (Johnson et al., 1967; Wilmore & Costill, 1973; Wilmore & Costill, 1974; Wilmore & Haskell, 1972). Two of these automated systems for assessing metabolic and respiratory function during exercise, one described by Kannagi et al., (1983) and Wilmore et al. (1976) and the other described by Norton (1982) and Versteeg and Kippersluis (1989), are reported in the literature as having used the Douglas bag technique or similar technique to determine the validity and reliability of the systems.

Johnson et al. (1967)

One of the first complete systems used to measure VO_2 is described by Johnson et al. (1967). This system used one of three respirometers to measure the volume of expired air depending on the amount of work being performed. At rest, the Tissot spirometer was used; for moderate exercise the Kofranyi-Michaelis respirometer; and for hard work, a high-capacity, low-resistance Parkinson-Cowan CD-4 dry gas meter. Samples of expired air were collected and stored in metalized bags which are impermeable to O_2 and CO_2 as well as water vapor. The collected samples of expired air were passed through a drying column attached to a paramagnetic O_2 meter and a thermal conductivity CO_2 meter.

Calibration of the three respirometers was completed by using the method described by Consolazio et al. (1963). The gas analyzers for measuring exact percentages of O_2 and CO_2 were calibrated using room air and a gas mixture containing O_2, CO_2, and N_2 which was previously analyzed with the Haldane apparatus. A metalized bag containing a sample of calibration gas was connected to the system after the room air had been analyzed and prior to the introduction of the unknown samples. Calibration curves were then drawn and percentages of O_2 and CO_2 calculated.

Wilmore and Haskell (1972)

Wilmore and Haskell (1972) used three different systems to measure the VO_2max of 20 professional football players. In five subjects a multistage bicycle ergometer test was used with a Parkinson-Cowan CD-4 high-velocity, low-resistance dry gas meter to measure inspired ventilation volumes. Beckman LB-1 and Beckman E-2 electronic gas analyzers were used for determining the CO_2 and O_2 content of the expired air samples. An additional five subjects performed an incremental treadmill test employing a Vertek VR 4000 pneumotach for assessing ventilation volumes, a Westinghouse fuel cell analyzer for determining O_2 percentage and a Goddart Capnograph for determining CO_2 percentage of the expired air. All measurements were entered into a PDP-12 computer, which allowed a continuous on-line analysis of all physiological data. Finally, 10 subjects completed a treadmill test using the same grade-incremented test as above. Ventilation volumes were assessed in duplicate using a Parkinson-Cowan CD-4 gas meter on the inspired side and a Vertak 4000 pneumotach. Gas analyses were also performed in duplicate using a Med-Spec mass spectrometer and Beckman LB-1 and E2 gas analyzers. The data were entered into a Raytheon 703 computer allowing an on-line analysis of the resulting physiological data.

In all systems, the respiratory gas analyzers were calibrated using standard gases, which had been periodically subjected to micro-Scholander analysis. The gas meters and pneumotach were calibrated before each run using either a calibration syringe or a Tissot spirometer. The subject breathed through either a triple-J or a Daniels' two-way valve (Daniels, 1971), with respiratory samples being obtained according to the method outlined by Wilmore (1968) or a mechanized version of the same method.

No comparisons were made between any of the systems for differences in metabolic measurements since subjects were only tested one time to get a VO_2max value.

Wilmore and Costill (1973)

In an attempt to determine the exact extent to which N_2 retention-production influences the calculation of VO_2 via the Haldane transformation during graded exercise, Wilmore and Costill (1973) used the following system to measure VO_2. The system consisted of a Daniels-type respiratory valve (Daniels, 1971), two Parkinson-Cowan CD-4, high-velocity, low-resistance dry gas meters to measure inspiratory and expiratory volumes, a mixing chamber to collect the expired air, a Med-Spec mass spectrometer, model MS-8 to measure O_2 and CO_2 gas percentages, and a Raytheon Computer (Model 703) to analyze the data. In addition, one minute samples of expired air were obtained as described by Wilmore (1968) and were analyzed with Beckman E-2 and Beckman LB-1 gas analyzers for O_2 and CO_2, respectively.

Both gas meters were calibrated at the beginning and at the conclusion of the study against a 120-liter Tissot spirometer, using pulsatile flow rates of 5, 20, 60, and 100 liters$\cdot$min^{-1}. Calibration factors were established independently for each gas meter at each flow rate. The difference between gas meters was small, and within a given meter for various flow rates, the calibration factor was essentially constant. Room air was sampled periodically with the mass spectrometer and cylinders of mixed gases of known concentration (via micro-Scholander analysis) were used to calibrate the analyzers between work loads.

Wilmore and Costill (1974)

One of the first mobile and relatively inexpensive systems for measuring VO_2 is described by Wilmore and Costill (1974). This system was compared to a computerized system described previously by Wilmore and Costill (1973). This semiautomated system consisted of a Parkinson-Cowan, CD-4 gas meter for the assessment of VE, a three way gas-sampling valve for aliquoting gas samples, Beckman OM-11 and LB-2 gas analyzers for O_2 and CO_2 analysis, respectively, and a Hewlett-Packard 9810 programmable calculator for data reduction.

Calibration of the respiratory gas analyzers was done by attaching a two liter rubber bag filled with one of several calibration gases (micro-Scholander method) to one end of a two-way metal stopcock. This stopcock was positioned next to the mixing chamber in the line that connected the three-way gas sampling valve to the mixing chamber. This procedure nearly duplicated the actual gas collection procedure used in the test, allowing the calibration gases to cross all fittings and joints, enabling the detection of any potential leaks in the system. A minimum of two calibration gases were used each time to check the linearity of the analyzers. The gas meter used in this system was calibrated against a 120-liter Tissot spirometer with pulsatile flows, at rates spanning the range from 20-200 liters$\cdot$min^{-1}.

However, during this study the only comparisons reported by Wilmore and Costill (1973) were the respiratory gas concentrations between the two methods. Out of 117 measurements the semiautomated system had a mean FeO_2 of 17.16 with a standard deviation of 0.28 compared to the computer based system mean FeO_2 of 17.18 and a standard deviation of 0.27. The comparisons of mean $FeCO_2$ were also nearly identical with the semiautomated system having a mean of 3.47 and standard deviation of 0.21, and the computer based system reporting a mean of 3.43 with a standard deviation of 0.20. Since VE comparisons of the two systems were not reported in the study it is impossible to determine the validity of the entire system.

Wilmore et al. (1976)

The Beckman Metabolic Measurement Cart (MMC) was evaluated against the same computerized system (Wilmore & Costill, 1973) and semiautomated system (Wilmore & Costill, 1974) previously described. The MMC is a complete system including individual analyzers or sensors for measuring oxygen, carbon dioxide, expired air volume, expired air temperature, barometric pressure, and time. However, only the measuring devices for oxygen, carbon dioxide, and expired air volume are relevant to this study and will be discussed. The MMC used a turbine for sensing expired gas volume and Beckman OM-11 (O_2) and LB-2 (CO_2) gas analyzers. A constant aliquot of the expired air (500 $ml \cdot min^{-1}$) was pulled from a mixing chamber which was located in the expired airstream, through a drying column and into the gas analyzers, and then returned to the mixing chamber prior to the gas passing through the volume transducer.

All three gas analysis systems were calibrated both before and after each test using calibration gases which were periodically analyzed by the micro-Scholander technique. The pre- and posttest calibration values for oxygen and carbon dioxide for all three systems were reasonably stable. The volume transducer of the MMC and the two Parkinson-Cowan gas meters were calibrated with a 120-liter Tissot spirometer both at the beginning and at the conclusion of the study. Air was pulsed from the Tissot spirometer through the two gas meters and into the MMC volume transducer, the four being connected in series. The calibration data for the volume transducer and the two Parkinson-Cowan CD-4 gas meters demonstrated that the Parkinson-Cowan meter in the computer system was the least stable of the three devices. This was due, primarily, to its underestimation of volumes at the lower end of the dynamic range of calibration.

All three systems were used simultaneously in 49 of the 122 tests. The remaining 63 tests were conducted using only the MMC and the computerized system. An exceptionally close relation was found among the three independent systems for FeO_2 and $FeCO_2$. For each metabolic level, not one of the comparisons resulted in differences between the systems which were statistically significant. Even the greatest observed differences for both FeO_2 and $FeCO_2$ were within the combined range of accuracy for any of the two analyzers being compared. Of the 60 paired comparisons for FeO_2, 40 were within 0.05 and 54 were within 0.10 percentage units. For $FeCO_2$, 54 of 60 paired comparisons were within 0.05 percentage units. A statistically significant difference for VE was noted only between the MMC and the computer system at the lowest two metabolic loads. Above the activity level of 4 METS, the individual differences between the three systems were always below 5%, and were frequently less than 2%. Statistically significant differences were found for VO_2 between the MMC and computer systems for the first five levels of work. When comparing the three systems simultaneously significant differences were found at only two of the lower work levels. The RER value demonstrated consistent agreement across all three systems.

Kannagi et al. (1983)

Since the study conducted on the Beckman MMC by Wilmore et al. (1976) may have been limited by high resistance to air flow with all systems being connected in series, Kannagi et al. (1983) conducted a study comparing measurements of the MMC with independent measurements using a method previously established by Bruce, Kusumi, and Hosmer (1973). The reference system used in the present study consisted of neoprene balloons to collect the expired gas, a respiratory test meter (American Meter Company DTM-115) to measure the expired volume, and Beckman OM-11 (O_2) and LB-2 (CO_2) gas analyzers to measure the concentrations of expired gas. The equipment used in the MMC to measure these same parameters were described earlier (Wilmore et al., 1976).

The gas analyzers in both systems were calibrated before each test using two reference gases previously analyzed by the micro-Scholander method and room air. Also, a comparison of the gas analyzers in each system was determined by making 14 simultaneous measurements of O_2 and CO_2 over the expected clinical range. The comparisons demonstrated no significant between the two systems.

Eight subjects, ages 31 to 64 years, performed symptom-limited multistage treadmill tests of submaximal and maximal exercise. Exercise tests were repeated randomly four times, twice with the MMC and twice with the manual method for measurements of aerobic requirements.

The two tests with the MMC were compared to one another as well as the two tests for the manual method to demonstrate reproducability of the methods. The four variables compared between each test were VE, VO_2, VCO_2, and RER. Paired data from the two tests for each variable at the third minute of each stage of exercise and at maximal exertion were compared. Excellent reproducability was found for both systems without any significant differences being reported.

Comparisons were also made between the two systems with the first MMC test paired with the first manual test and the second MMC test paired with the second manual test. Again, paired comparisons were made between variables at the third minute of each stage of exercise. High correlations were reported for VE, VO_2, and VCO_2, .97, .98, and .99, respectively. A lower correlation, .93, was reported for RER. Oxygen consumption and carbon dioxide production were significantly higher in the MMC compared to the manual method.

Norton (1982)

The MMC Horizon System, the successor to the previously described MMC (Wilmore et al., 1976), was evaluated using physical standards, a standard artificial lung (SAL), and two referee systems (Norton, 1982). One referee system used bag collection, aliquot gas measurements, and volume measurement with a Tissot spirometer. Only these results will be reviewed.

The MMC Horizon System differs from other automated devices, because it is a single integrated instrument rather than an assembly of individual analyzers. Included in the MMC Horizon System is an INTEL 8085A microprocessor which controls all the transducers, sensors, and other devices of the system. Like the MMC, the MMC Horizon System has sensors and transducers for the detection and measurement of volume, oxygen and carbon dioxide partial pressures, temperature, and pressure. However, only the equipment used to measure volume, oxygen, and carbon dioxide will be discussed.

Oxygen is measured with a temperature-controlled, fast response, polarographic sensor. Carbon dioxide is measured with a dual-beam non-dispersive infrared optical system with a pneumatic detector. The volume of air passing through the system is measured with a jewel-mounted turbine which incorporates electro-optical detectors. The expired gas goes through the mixing chamber into an assembly for measuring expired volume. The gas is then sent to one of six sampling sites determined by the microprocessor and is drawn through the O_2 and CO_2 sensors at a nominal flow rate of 500 $ml \cdot min^{-1}$.

The gas sensors in the MMC Horizon System are calibrated by sampling a "zero" gas (100% N_2) and a precision calibration gas (usually 4% CO_2 and 16% O_2) analyzed by the micro-Scholander method. The processor sets the ZERO and GAIN of the O_2 and CO_2 channels to these factors and uses them for subsequent measurements. To calibrate the volume transducer, the user connects the outlet of the integral pump to the inlet of the mixing chamber. The pump is then manually actuated by the user to deliver volumes to the transducer. Eight strokes of the pump are delivered at each of the three different flow rates. The microprocessor counts the strokes and accepts them if properly delivered, or it instructs the operator to adjust the flow rate. The microprocessor then performs a linearization of the volume.

For comparison, simultaneous measurements were made on the MMC Horizon System and a bag collection referee system using expired air samples from human subjects at rest and during steady-state exercise. The two measurement systems were in series, with the outlet of the MMC filling a meteorological balloon. Minute volume measurements were made by the referee system with a Tissot spirometer and concentration of gases in the balloon were measured with separate gas analyzers (Beckman LB-2 and OM-11) which had been independently calibrated with precision calibration gas analyzed by the Scholander method.

Eight subjects were tested during progressively increasing workloads on an electrically braked bicycle ergometer. Extremely high correlations between the two systems for VE (0.9973), VO_2 (0.9930), and VCO_2 (0.9979) were reported. However, the highest VE (BTPS) compared between the two systems was only 85 liters·min^{-1}. This low VE comparison does not test the entire range of volumes usually encountered when testing human subjects to maximum fatigue. Direct comparisons were not made between the two systems for gas concentrations since only the calculated VO_2 and VCO_2 were compared.

Versteeg and Kippersluis (1989)

Three systems were evaluated for measurement of O_2 uptake and compared to the conventional Douglas bag method. One system (9000 IV Ergometric System) was only tested with respect to its oxygen kinetics and will not be described. The other two (MMC-Horizon and EOS-Sprint) were tested during three exercise programs: (1) steady-state exercise, (2) progressive increasing exercise to maximal load, and (3) single-step exercise.

An electronically braked bicycle ergometer (Lode, type: Lanoy) in which adjustment of the load was rate-dependent. The air expired by the subjects was collected in bags or directly exhaled into the systems to be tested through a low-resistance respiratory valve (Hans Rudolph, 2700).

In the Douglas bag method, gas was collected into the bags for 15 to 30 seconds. At the end of the test, a sample was taken with a centrifugal pump from each bag which was analyzed for O_2 (paramagnetic; Servomex 570A Sybron; accuracy within 0.1%) and CO_2 content (infrared absorption; capnometer, Godart 146; accuracy within 0.2%). Oxygen and carbon dioxide analyzers were calibrated twice daily with test gases which were regularly checked with the micro-Scholander method. Gas volumes were measured with a wet gasometer (Schlumberger; accuracy within 50 ml).

The MMC-Horizon system was described previously (Norton, 1982).

The EOS-Sprint system uses a pneumotachograph (Jaeger) to measure expired ventilation volumes. The expired air subsequently passes through a mixing chamber where O_2 (paramagnetic) and CO_2 (infrared absorption) are continuously sampled. Calibration of the gas analyzers is completed using two test gases which are checked by the micro-Scholander method. The pneumotachograph is calibrated manually with a one liter syringe that comes with the machine.

No significant difference was found between the VO_2max obtained with the MMC-Horizon system and the Douglas bag method. The same results were found when comparing the EOS-Sprint system and the Douglas bag method. However, the differences between the MMC-Horizon system were always higher while the differences for the EOS-Sprint system were always lower than the Douglas bag method.

Development and Evaluation of the Q-Plex

The Q-Plex was developed by the Quinton Instrument Company in 1987 to provide a totally automated assessment of respiratory and metabolic parameters during exercise. This system uses a nonrebreathing valve and mixing chamber for the collection and mixture of expired gas, a differential pressure pneumotachometer for the measurement of VE, and electronic gas analyzers for the measurement of FeO_2 and $FeCO_2$. With this system immediate data analyses are available, fewer technicians are needed to complete the test, and many tests can be completed in a minimal amount of time compared to the Douglas bag technique. However, the only published literature on the validation of this system is by the designers of the machine itself (Quinton, 1988) and Chypchar, Jones, Obminski, and Bradley (1989).

Quinton (1988)

In order to validate and verify the Q-Plex hardware and software, simultaneous collection and measurement of pulmonary gas exchanges were performed with Douglas bag methodology. The two systems were connected in series to allow expired air to flow through the Q-Plex and into the bag. The expired air was measured for volume, mixed expired oxygen, and mixed expired carbon dioxide by on-line analysis in the Q-Plex. Bags were collected from the exhaust port of the Q-Plex mixing chamber simultaneously during four levels of steady-state exercise. Bag volumes were measured by Tissot spirometer and gases analyzed by independent O_2 and CO_2 analyzers. Oxygen uptake, CO_2 production, and RER were subsequently calculated. Parameters calculated by the Q-Plex were compared with those calculated from the Douglas bag data. A total of eight treadmill trials were performed. Each trial was during the 4th and 5th minutes of a 6 minute submaximal steady-state run on the treadmill.

Excellent correlation coefficients of 0.9993, 0.9997, and 0.9938 were reported for VO_2, VCO_2, and RER, respectively. However, like the study on the MMC Horizon System, ventilation volumes were only compared up to 100 liters$\cdot$min^{-1} which is only the middle of the range (5 - 200 l$\cdot$min^{-1}) which many large athletic subjects ventilate during a VO_2max test. It would be hard to call the Q-Plex volume device valid at higher levels since it has not been tested at these higher values. The gas percentages were not compared directly with a correlation but it appears that the percentages of the Q-Plex are as good as the reference system with such high correlations for VO_2 and VCO_2 being reported.

Chypchar et al. (1989)

Chypchar et al. (1989) compared the Q-Plex to the McMaster University system for accuracy and precision of O_2, CO_2, and volume measurements. All subjects were tested at rest, 25%, 50%, and 75% of their previously determined VO_2max. Thirty-five Douglas bags were collected for analysis and validation for the following parameters: FeO_2, $FeCO_2$, VE, VO_2, VCO_2, and RER. Before each test the McMaster mass spectrometer system was calibrated using three concentrations of gas previously analyzed by the Lloyd-Haldane apparatus. The Q-Plex was also calibrated using two precision calibrated gas mixtures.

Subjects breathed through a low resistance, low deadspace valve and expired gas was routed through low resistance tubing to the Q-Plex. Subjects cycled on a Siemens Elema cycle ergometer for five minutes steady state at each workload. During the last minute of each workload, the McMaster referee system sampled mixed expired gases in consecutive intervals from the expired gas port on the Q-Plex. Simultaneously, expired gases were collected in Douglas bags for volume comparisons. Bag volume was measured through a calibrated dry gas meter and total volume displacement recorded on a Siemens Elema mingograph. Referee system gas samples were averaged for the collection period and compared to the time matched Q-Plex values for FeO_2 and $FeCO_2$ and corresponding expired gas volume in Douglas bags.

Results of gas analysis demonstrated a correlation coefficient between the Q-Plex and the McMaster mass spectrometer system of 0.993 and standard errors of 0.02% absolute. Results of VE comparison also yielded high correlation (0.991) with the McMaster dry gas meter and a standard error of 1.01 liters. Comparison of calculated parameters of VO_2, VCO_2, and RER yielded no significant differences between the two systems with concurrent validity coefficients ranging from 0.997 to 0.999 for VO_2 over the range of workloads.

Summary

The preceding review of related literature has shown that bag collection techniques for containment of expired air with volumes measured via mechanical gas meters are considered to be standard methods for comparison purposes in the validation of metabolic measurement systems which measure VE, FeO_2, and $FeCO_2$ (Beaver et al., 1973; Consolazio et al., 1963; Kannagi et al., 1983; Norton, 1982; Norton et al., 1976; Versteeg & Kippersluis, 1989; Wilmore & Costill, 1974; Wilmore et al., 1976). Also, many complete systems have been developed to assess these metabolic functions, but validation data and procedures of these systems are somewhat incomplete (Johnson et al., 1967; Wilmore & Costill, 1973; Wilmore & Costill, 1974; Wilmore & Haskell, 1972). Only four studies (Kannagi et al., 1983; Norton, 1982; Versteeg & Kippersluis, 1989; Wilmore et al., 1976) provided complete validation procedures and data.

Since many of the systems presented above, as well as newer systems like the Q-Plex, do not have large quantities of validation data in the literature, it was the purpose of this study to establish the validity of the Q-Plex before it was put to routine use.

CHAPTER III

METHODOLOGY

Subject Selection

Twenty-seven males from the University of Wisconsin-La Crosse, ranging from 19-34 years of age, volunteered to participate in this study. Volunteers were accepted without prior fitness level assessment by the actual testers although only subjects with previously tested VO_2max levels of 55 $ml \cdot kg^{-1} \cdot min^{-1}$ or higher participated in this study. Subjects were also requested to be medication free and were assumed to be in good health.

Preparatory Procedures

Subjects were personally contacted on an individual basis and briefed regarding testing preparations, conditions, and objectives. Subjects were asked to eat normally until 2 hours prior to the test and were also requested to avoid strenuous exercise for at least 5 to 6 hours prior to testing to avoid premature termination of the test. Finally, subjects were requested to dress in appropriate running attire.

Test Measurement Procedures

Upon arrival at the UW-L Human Performance Laboratory, subjects were presented with informed consent materials (see Appendix A) and given a brief explanation of testing procedures. Detailed explanation of each aspect of the testing process was provided as the subject was guided through the testing procedure.

Preliminary Studies

The procedures used in this study were chosen because they allow exactly 1 minute of ventilation to be measured, a full minute of expired gas to be collected in a meteorological balloon (model 5301, 300 gram - Weather Measure Corporation, Sacramento, CA), and a sample of this gas transferred from the balloon into a Bailey bottle for gas analysis (Kjellberg & Fayette, 1968) within 1 minute of collection.

To determine the effect on the gases contained in the balloon, the investigator filled a meteorological balloon with a known gas concentration which had been previously determined on several occasions by the micro-Scholander technique (Scholander, 1947). The gas concentrations in the balloon were determined over a 60 minute period using the gas analyzers in a Beckman Metabolic Measurement Cart (MMC1 - Beckman Instruments, Anaheim, CA). The oxygen analyzer (model OM-11) and carbon dioxide analyzer (model LB-2) were calibrated before and after the investigation with known gases standardized by the micro-Scholander technique. Table 1 presents data collected during this pilot study.

Table 1. Diffusion Rate of O_2 (16.02%) and CO_2 (4.00%) through a Meteorological Balloon with Time.

Time (min)	% O_2	% CO_2
5	16.02	4.00
10	16.02	3.99
20	16.02	3.98
30	16.01	3.95
40	16.02	3.93
50	16.02	3.90
60	16.03	3.88

Table 1 shows the percentage of CO_2 in the meteorological balloon was not affected until sometime after the fifth minute, and the percentage of O_2 remains fairly constant even after 1 hour of remaining in the balloon. Therefore it was concluded that the meteorological balloon was an acceptable container for the expired gas for at least 1 minute.

The Parkinson-Cowan meter (model CD4 - Carl Poe Co., Inc., Houston, TX) used in this study to measure expired gas volumes was calibrated against a 120 liter Tissot spirometer (see Appendix B for calibration data). This calibration was done by pumping known volumes of room air through the Parkinson-Cowan meter by way of a 3.002 liter syringe pump. The air was then routed through tubing from the exhaust port of the Parkinson-Cowan meter into the 120 liter Tissot spirometer. The volumes (ATPS) determined by the two methods were then compared using a paired t-test (see Table 2) and a Pearson product-moment correlation (see Figure 1).

Table 2. Comparison of Parkinson-Cowan Meter Mean Volumes versus Tissot Mean Volumes (L)*.

	P-C meter (N=60)	Tissot (N=60)	% error
Mean	46.8233	46.8275	0
Standard deviation	26.3745	26.3686	

* Range = 0 to 90 liters

Since the means were not statistically ($p > 0.05$) different and this comparison produced such a high correlation ($r = .9997$), the calculated correction factor (Tissot = .999682 x P-C meter + .019039), which was derived to convert the gasometer to Tissot readings, was not used.

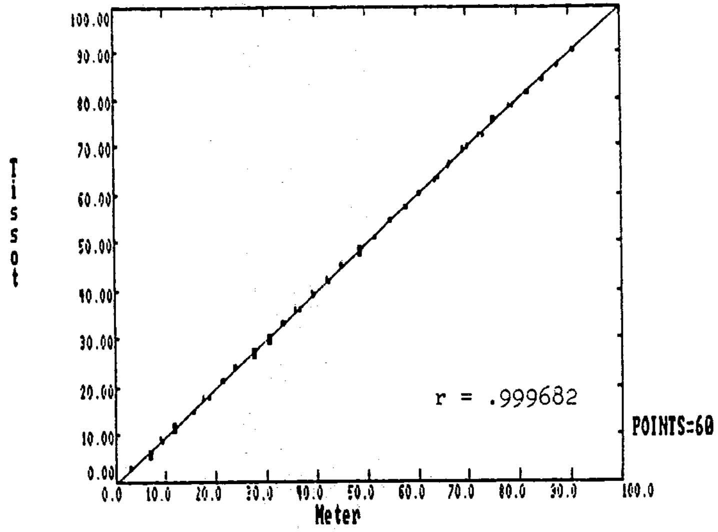

Figure 1. Parkinson-Cowan Meter versus 120 liter Tissot Spirometer

A second pilot study was conducted to determine if the above procedures altered the gas fractions. A meteorological balloon was filled with a known concentration of O_2 (16.02%) and CO_2 (4.00%). The gas in the balloon was then drawn through the Parkinson-Cowan meter with a vacuum pump and passed through the exhaust port of the pump. A small sample of the gas was collected in a Bailey bottle and analyzed at least two times by the standard micro-Scholander gas analysis method. The gas sample analyzed had an O_2 percentage of 16.03 and a CO_2 percentage of 3.99 compared to the initial values of 16.02 and 4.00%. These data show the gas concentrations were minimally affected by this method of gas collection and analysis.

Collection of Gas Samples

In order to validate the Q-Plex hardware and software, simultaneous collection and measurement of pulmonary gas from exercising human subjects were obtained with a meteorological balloon gas collection methodology as described later in this Chapter.

The subjects ran on a motor driven treadmill (model 24-72 - Quinton Instrument Co. Seattle, WA) in accordance with the protocol defined in Appendix D. This treadmill protocol used a constant speed of 8 mph and a grade which started at 0% and was increased 3.0% every 3 minutes. A 5 minute warm-up of 3.5 mph and 10% grade preceded the run. Gas was collected in a meteorological balloon for 1 full minute during at least three different levels of exercise: low steady state, medium steady state, and at maximal exertion.

Q-Plex

During the test the subjects breathed through a low resistance, low dead space (115 mls) valve (model 2700 - Hans Rudolph, Inc., Kansas City, MO). The expired gas was routed through low resistance tubing (3.5 cm x 274 cm long) to the Q-Plex. Within the Q-Plex, the expired gas passed through a heated-grid, differential pressure pneumotachometer (model 3813 - Hans Rudolph, Inc., Kansas City, MO) which provides a voltage signal that varies with flow rate. The signal processing and computer algorithms performed by the Q-Plex to convert the pneumotach readings to volumes were not available to the researchers. The expired gas was then routed into a 5.5 liter mixing chamber where .364 liters of gas per minute was removed continuously and conveyed (without removal of water vapor) to the O_2 and CO_2 analyzers for on-line analysis of mixed expired oxygen and mixed expired carbon dioxide. The specific methods by which the Q-Plex accounts for water vapor and converts the wet gas to standard temperature, pressure dry, were not available.

Meteorological Balloon Method

After passing through the mixing chamber, the gas traveled out the exhaust port of the Q-Plex and through a calibrated Parkinson-Cowan meter where the expired volume was measured during the last minute of each steady state stage, and collected in a meteorological balloon. When full, the meteorological balloon held at least 210 liters of gas which was adequate enough to hold the largest minute ventilation volume.

Within 1 minute after collection of gas, the gas was drawn from the balloon with an electric vacuum pump. During the first 5 seconds of emptying the balloon, some gas was released into the room allowing for any room air that might have been in the connecting tubing and the neck of the balloon to be evacuated. A cork was then placed in the outlet side of the vacuum pump forcing the collected gas through a piece of surgical tubing that was attached to a barbed nipple on the outlet side of the vacuum pump. For approximately 10 seconds gas was then pushed through the surgical tubing to flush it out. After the surgical tubing was completely flushed out it was connected to a Bailey bottle and a small sample (70-80 ml) of gas was collected for analysis of FeO_2 and $FeCO_2$ by the standard micro-Scholander method (see Appendix C for procedure). The gas analysis was completed under the supervision of an experienced technician who had routinely performed the procedure for more than 10 years. At least three Bailey bottles were collected from each subject. The barometric pressure, temperature, and time of the expired gas collection were measured with a mercury barometer, an NBS certified thermometer, and a stopwatch, respectively.

Statistical Treatment of the Data

Minute ventilation volume, oxygen uptake, carbon dioxide production, and respiratory exchange ratio were subsequently calculated (see Appendix D for equations). Gas exchange data calculated by the Q-Plex were compared with those calculated from the meteorological balloon data using paired t-tests and Pearson product-moment correlations.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The assessment of metabolic and respiratory function in human subjects during exercise has been made easier and faster to perform with the help of advances in technology. A new instrument, the Q-Plex I Cardiopulmonary Exercise System developed by the Quinton Instrument Company (Seattle, WA), determines, displays, and prints ventilation volumes, fractional concentrations of expired oxygen, and fractional concentrations of expired carbon dioxide in "real time" allowing for immediate diagnosis and feedback to the subject. Since this instrument is relatively new (1987), its validity has yet to be established. The purpose of this study was to determine the validity of the Q-Plex based on comparing the Q-Plex data to data obtained from meteorological balloon gas collection methodology.

This chapter presents the results of the study, and how they relate to previous literature. Included are descriptive characteristics of the subjects and comparisons of gas exchange data measured by the meteorological balloon method versus the Q-Plex.

Descriptive Characteristics of Subjects

The Q-Plex was evaluated in the Human Performance Laboratory at the University of Wisconsin-La Crosse. A total of 27 highly trained male runners and cyclists volunteered to participate in this evaluation. Only 20 subjects were used in the final data analysis because of technical difficulties during early testing of the first seven subjects. However, a minimum of three gas samples were collected on each subject and a maximum number of six were obtained on some individuals allowing for a total of 93 gas samples to be compared by the two methods. Descriptive and physiological characteristics for the 20 subjects are presented in Table 3.

Table 3. Descriptive and Physiological Characteristics of Subjects (N=20).

Variable	Mean	SD	Range
Age (years)	23.2	3.49	19-34
Height (cm)	179.1	6.96	165.1-193.0
Weight (kg)	73.0	9.49	57.0-91.4
[a]VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$)	64.5	7.69	50.0-77.3
[a]V_Emax BTPS ($liter \cdot min^{-1}$)	144.3	30.43	78.8-206.8

[a] Data based on Q-Plex

The VO_2max ($ml \cdot kg^{-1} \cdot min^{-1}$) and VE BTPS ($liter \cdot min^{-1}$) data in Table 3 are based on measurements made by the Q-Plex. The last minute during the final completed stage of the treadmill protocol (see Appendix E) was used for the maximal data. These values represent a subject population having a high range of ventilation volumes which is necessary to test the pneumotach in the Q-Plex at low, medium, and high ventilation volumes.

Validation of the Q-Plex

Each of the subjects participated in a constant speed, grade-incremented treadmill test to volitional exhaustion. Simultaneous measurements on expired air were performed with the Q-Plex and the meteorological balloon gas collection methodology.

Gas Fractions

The overall means, standard deviations, and per cent error between the two methods of measurement for FeO_2 and $FeCO_2$ are presented in Table 4. Also in Table 4 is the gas exchange data compared during the various workloads. Figures 2 and 3 illustrate the bivariate distribution for FeO_2 and $FeCO_2$.

Table 4. Comparison of FeO_2 and $FeCO_2$ According to Workloads and Overall Measurements.

Stage			FeO_2			$FeCO_2$		
MPH	Incline	N	Balloon	Q-Plex	% error	Balloon	Q-Plex	% error
3.5	10%	19	15.70[1] .35[2]	15.63 .36	-0.4	4.65 .29	4.74 .34	1.9
8.0	0%	20	15.93 .46	15.85 .53	-0.5	4.58 .38	4.62 .43	0.9
8.0	3%	20	15.99 .44	15.95 .43	-0.3	4.65 .35	4.67 .34	0.4
8.0	6%	19	16.23 .52	16.28 .55	0.3	4.58 .43	4.60 .46	0.4
8.0	9%	12	16.54 .50	16.54 .49	0.0	4.56 .44	4.55 .43	-0.2
8.0	12%	3	16.64 .42	16.64 .38	0.0	4.62 .43	4.56 .39	-1.3
Overall		93	16.08 .53	16.03* .56	-0.3	4.61 .37	4.64* .39	0.7

[1] mean
[2] SD
* ($p < 0.05$)

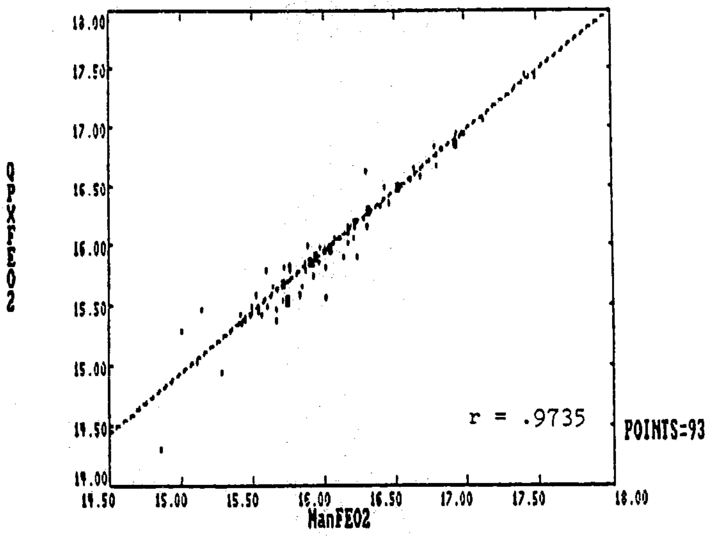

Figure 2. Balloon Method FeO_2 versus Q-Plex FeO_2.

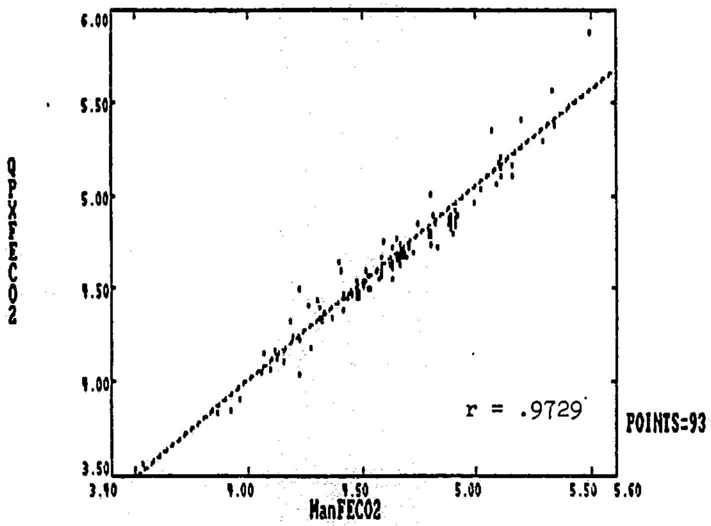

Figure 3. Balloon Method $FeCO_2$ versus Q-Plex $FeCO_2$.

Overall the Q-Plex mean values (Table 4) for FeO_2 and $FeCO_2$ were significantly ($p < 0.05$) different from the balloon method. However, the .05% and 0.03% (absolute percents by volume) mean differences for FeO_2 and $FeCO_2$ for these measurements are acceptable because they are within the measurement error of the analyzers being compared. The Q-Plex gas analyzers are reported as having an accuracy of ± .05% (absolute volume percent). Allowing the ± .015% (absolute volume percent), accuracy of the micro-Scholander method and the two systems agree very well. Furthermore there was a high correlation for both the FeO_2 ($r = .9735$) and $FeCO_2$ ($r = .9729$) between the two methods.

This good agreement found between the two systems for FeO_2 and $FeCO_2$ is similar to the results reported in the literature for other metabolic systems. Wilmore and Costill (1973) reported less than a 1% difference for FeO_2 compared to the computer based reference system and a 1.2% difference for $FeCO_2$ comparisons. Wilmore et al. (1976) also found the Beckman MMC OM-11 (O_2) and LB-2 (CO_2) gas analyzers to be within 0.10 percentage units of either reference system they were compared to. Kannagi et al. (1983) reported no significant ($p > 0.05$) differences between the MMC and the manual reference system, but this was expected because both systems used Beckman OM-11 (O_2) and LB-2 (CO_2) analyzers to measure expired gas concentrations. However, when the Q-Plex gas fractions were validated against the McMaster University system (Chypchar et al., 1989) relatively higher correlations than the present study for O_2 ($r = .997$) and CO_2 ($r = .996$) were reported.

VE (BTPS)

As indicated previously, there are numerous methods reported in the literature for the determination of minute ventilation volumes (Consolazio et al., 1963; Jones et al., 1975; Norton, 1976). Over the years the most accepted method has been to collect the entire expired volume into a Tissot spirometer. Due to the expense and awkwardness of using Tissot spirometers, numerous other methods have been employed for determining minute ventilation volumes such as Douglas bags, meteorological balloons, and gas meters. Although using the Tissot spirometer may have been the preferable method, the 120 liter Tissot spirometer available to the researcher was not large enough to measure the high ventilation volumes necessary to establish the validity of the Q-Plex at the volumes often found in highly trained individuals. For this reason it was decided to use a Parkinson-Cowan meter to determine expired ventilation volumes.

As indicated in the previous chapter, a pilot study was conducted to compare the volumes obtained using the Parkinson-Cowan meter with those obtained in the Tissot spirometer. This initial comparison indicated that there was an extremely high correlation ($r = .9997$) between these methods and a near zero y-intercept from regression indicating that the Parkinson-Cowan meter measured ventilation volumes accurately. Although the Parkinson-Cowan meter was originally designed as a dry gas meter to be used on the inspired side, it was placed on the expired side in this study. This arrangement was used in the belief that it would reduce the chance for leakage and/or measurement error. It was, therefore, assumed that if the Parkinson-Cowan meter was thoroughly dried out after each test the volumes obtained using the Q-Plex system could be validated against those obtained with the

Parkinson-Cowan meter.

When the ventilation volumes were compared using this procedure, there was a consistent difference between volumes, with the Q-Plex yielding higher values. A possible reason for this difference may have been that the Parkinson-Cowan meter was used on the expired side. Therefore, a second series of measures were made comparing ventilation volumes using the Parkinson-Cowan meter on the inspired side to those of the Q-Plex. For this purpose, four subjects ran a grade-incremented treadmill test using the Parkinson-Cowan meter to measure inspired volumes while simultaneous volumes were collected by the Q-Plex (see Appendix F for actual data). A total of 52 ventilation volumes were made and compared between the two methods. The actual volumes (BTPS) determined by the two methods were then compared using a paired t-test (see Table 5) and Pearson product-moment correlation (see Figure 4).

Table 5. Comparison Between Inspired Volume Measurement of Parkinson-Cowan Meter to the Q-Plex (L).

	P-C meter VE (BTPS) (N=52)	Q-Plex VE (BTPS) (N=52)	% error
Mean	75.9212	81.9308*	8.9
Standard deviation	30.7383	34.2484	

* ($p < 0.05$)

The P-C meter VE (BTPS) volumes in Table 5 are based on the VI (ATPS) corrected to VE (BTPS) using the ambient conditions presented in Appendix F.

Again the Parkinson-Cowan meter consistently resulted in lower VE volumes than the Q-Plex. The means for the two methods were significantly ($p < 0.05$) different and the 8.9 % error was even higher than the 6.0 % error found using the Parkinson-Cowan meter

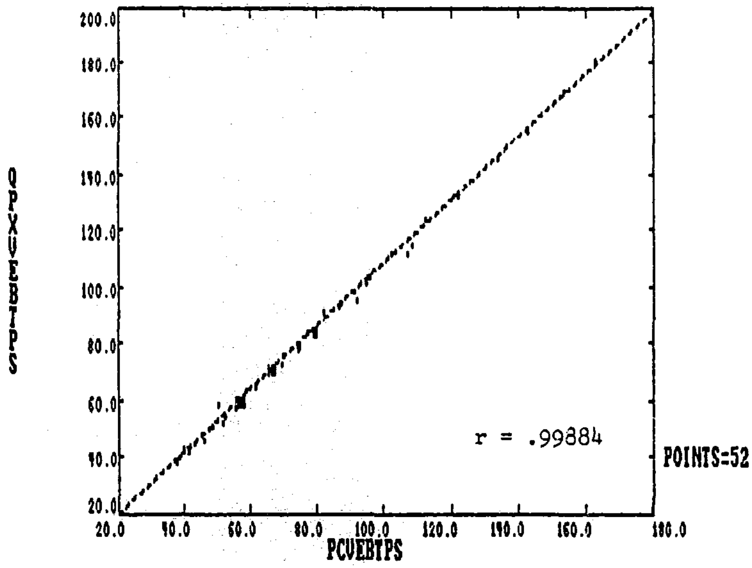

Figure 4. Inspired Volume Measurement of Parkinson-Cowan Meter to the Q-Plex (L).

on the expired side during the actual validation study.

After all the validation data were collected a final comparison was made between a series of volumes obtained with the Parkinson-Cowan meter and the Tissot spirometer. These results indicated that there was a much larger discrepancy in volumes obtained between these methods than those initially obtained. These differences were of sufficient magnitude to question the accuracy of using the Parkinson-Cowan meter to validate the volumes obtained with the Q-Plex. Since it was impossible to determine the cause of this error, or at what point in the study it occurred, the ventilation volumes of the Q-Plex could not be legitimately validated using this Parkinson-Cowan meter. Unfortunately, since the accuracy of measuring VO_2 and VCO_2 is dependent upon ventilation volumes, neither of these variables could be accurately compared.

Discussion

The testing of a system such as the Q-Plex presents certain procedural and conceptual challenges. First is choosing the referee system to which the Q-Plex is to be compared. Although there are standard methods for measuring the variables evaluated by the Q-Plex, there is no single process which can measure all of the variables measured by the Q-Plex over the range and under the operating conditions in which it is intended to function. This challenge was approached by testing the Q-Plex against a standard meteorological balloon gas collection system to directly compare the measurement of VE, FeO_2, $FeCO_2$, VO_2, VCO_2, and RER. However, since the Parkinson-Cowan dry gas meter used to measure VE was discovered to be inaccurate some time after all data were collected, the experimenter could not justify presenting data that may be questionable. The small per cent difference in the Q-Plex measurement for FeO_2 and $FeCO_2$ are acceptable because they are within the measurement error of the analyzers being compared. From these results, it can be concluded that the measurements made by the gas analyzers in the Q-Plex are as accurate as the standard micro-Scholander technique, but the Q-Plex was able to determine the values significantly faster than the micro-Scholander method. This is important since gas fractions for each breath are determined by the Q-Plex.

The challenge in performance testing of the Q-Plex is the use of statistical procedures for demonstrating equivalent performance between the new system and the reference system. Even if the mean values for the gas fractions between the two systems were not statistically different, theoretically it could not be established that the Q-Plex is the same as the meteorological balloon system. The best that could have been done is to use statistical techniques in a descriptive sense to compare the variability of the two systems. This is important to note since the meteorological balloon system used does not report absolute measurements; it, too, has some variability and error.

The best test of a system such as the Q-Plex is its performance in its intended application of assessing respiratory and metabolic parameters of subjects during rest and exercise. The Q-Plex has capabilities for printing and plotting data during and after exercise tests which eliminates the tedious process of data reduction and analysis required with manual methods and also allows for immediate feedback to the subject. Fewer technicians are needed to complete a test and the automation in the Q-Plex makes the system easy to calibrate, operate, and understand. With only slight training the menu system (i.e., press this to calibrate...press this to start...press this to stop...) allows any operator to achieve the same accuracy.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The primary purpose of this study was to determine if the Q-Plex I Cardiopulmonary Exercise System developed by Quinton Instrument Company (Seattle, WA) was an accurate system for measuring expired concentrations of oxygen, expired concentrations of carbon dioxide, and expired gas volumes to determine oxygen consumption, carbon dioxide production, and respiratory exchange ratio.

Twenty-seven highly trained male runners and cyclists between the ages of 19 and 34 years volunteered to participate in this validation study. Each subject performed a constant speed, grade-incremented treadmill test to volitional exhaustion. Simultaneous measurements on expired air were performed with the Q-Plex and a meteorological balloon gas collection system which employed the use of the micro-Scholander technique to analyze the gas fractions and a Parkinson-Cowan meter to determine VE. The physiological parameters measured by the two systems during the actual treadmill tests included FeO_2, $FeCO_2$, VE, VO_2, VCO_2, and RER.

The statistical analyses included means, standard deviations, and ranges for the physical characteristics of all subjects. Comparisons between the meteorological balloon method and the Q-Plex for all the physiological parameters measured were made using paired t-tests and Pearson product-moment correlations. The level of significance was set at 0.05 for the statistical tests.

Conclusion

Although there was a statistically significant difference between the gas analyzers used in the Q-Plex for measuring expired concentrations of oxygen and carbon dioxide and the micro-Scholander chemical gas analyzer used in the meteorological balloon method, these differences were within the measurement error of the analyzers being compared. Based upon these results it was concluded that the individual gas analyzers within the Q-Plex demonstrate comparable results to the micro-Scholander chemical gas analyzer. However, due to instrumentation problems, the reference system used to measure VE was found to be inaccurate thus not permitting a valid comparison to be made between the collected VE data or the calculated parameters of VO_2, VCO_2, and RER.

Recommendations

The following recommendations are offered for future considerations:

1. In a validation study such as this one, it is imperative that all instruments be calibrated before and after each individual test continuously throughout the course of the study.

2. Another validation study should be completed on the Q-Plex using a 300 liter Tissot spirometer for comparing the expired gas volumes. This would enable the researcher to collect a full minute of expired gas in the Tissot spirometer allowing for an accurate measurement of VE to be made for comparison with the Q-Plex.

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APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT FORM

The University of Wisconsin-La Crosse
La Crosse, Wisconsin

A VALIDATION STUDY ON THE Q-PLEX I CARDIOPULMONARY EXERCISE SYSTEM DEVELOPED BY THE QUINTON INSTRUMENT COMPANY

(William G. Davey)

I,_______________, volunteer to participate in the Q-Plex validation study being conducted in the Human Performance Laboratory at the University of Wisconsin-La Crosse. I understand that the participation in this study will involve one visit to the Human Performance Laboratory. At the testing time I will have body weight measured and run a maximal treadmill test to measure maximal aerobic capacity.

I understand that the maximal aerobic test consists of a run to voluntary exhaustion on a motor-driven treadmill. The speed and the incline of the treadmill will be gradually increased throughout the run. During this test heart rates will be monitored with an Unique Heart Watch Monitor and exhaled air will be collected. This test requires a maximal effort, however, I can terminate the run any time I wish. As with any exercise, there exists the possibility of adverse changes (i.e.: dizziness, etc.) to occur during the test. If any abnormal observations are noted, the test will be terminated immediately.

To my knowledge I am not infected with any disease or have any limiting physical conditions or disabilities, especially with respect to my heart, that would preclude such a strenuous exercise.

The actual testing will be conducted by William G. Davey, a graduate student in the Adult Fitness/Cardiac Rehabilitation program at the University of Wisconsin-La Crosse. He will be under the supervision of Nancy Kay Butts, Ph.D.

I,_______________, approve of the procedure as explained for the Q-Plex validation study at the University of Wisconsin-La Crosse's Human Performance Laboratory and agree to participate. I have read the foregoing and understand it. Any questions which may have occurred to me have been fully answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, or by anyone acting on behalf of them.

Signed:____________________ Date:__________________

Witness:___________________ Date:__________________

APPENDIX B

CALIBRATION OF PARKINSON-COWAN GAS METER

CALIBRATION OF PARKINSON-COWAN GAS METER

The volume gas meter used in this study was calibrated against a 120 liter Tissot spirometer. Calibration was done by pumping a known volume of room air through the volume gas meter (via a 3.002 liter syringe pump) which was then routed through tubing from the exhaust port of the gasometer into the 120 liter Tissot spirometer. The volumes determined by the two methods were then compared. The following data were recorded on two different days which made it necessary to calculate two different correctional factors to allow for the differences in ambient conditions. Day one conditions are in normal type and day two conditions are in bold type.

Barometric Pressure =	750	742
Room Temperature (C) =	23.9	21.9
Wet Bulb (F) =	54	54
Dry Bulb (F) =	75	72
Relative Humidity =	22	29

$$\text{Tissot} \times .1332 \ \frac{(750 - 22)}{(750 - 5)} = .1302$$

$$\text{Tissot} \times .1332 \ \frac{(742 - 20)}{(742 - 6)} = .1307$$

Parkinson-Cowan Meter				Tissot			
Pumps	End	Start	Change (liters)	End	Start	Change (mm)	Volume (liters)
1	92.9	89.5	3.0	30	7	23	2.99
1	41.8	39.0	2.8	77	54	23	3.01
2	99.0	92.5	6.5	77	30	47	6.12
2	37.4	30.9	6.5	383	337	46	5.99
3	108.3	99.0	9.3	75	5	70	9.11
3	89.8	80.8	8.9	449	379	70	9.15
4	19.8	8.3	11.5	168	75	93	12.11
4	69.8	58.3	11.5	165	73	92	11.98
5	35.5	19.8	15.7	167	51	116	15.10
5	38.9	23.3	15.6	435	319	116	15.16
6	53.1	35.5	17.6	212	73	139	18.10
6	88.4	69.8	18.6	303	165	138	17.97
7	74.6	53.1	21.5	375	212	163	21.22
7	69.1	48.0	21.1	213	49	164	21.43

Parkinson-Cowan Meter				Tissot			
Pumps	End	Start	Change (liters)	End	Start	Change (mm)	Volume (liters)
8	98.7	74.6	24.1	239	54	185	24.08
8	112.1	88.4	23.7	488	303	185	24.08
9	126.0	98.7	27.3	448	239	209	27.21
9	66.3	38.9	27.4	260	51	209	27.32
10	56.3	26.0	30.3	678	448	230	29.95
10	67.7	37.4	30.3	429	198	231	30.08
11	89.2	56.3	32.9	336	80	256	33.33
11	123.3	89.8	33.5	319	63	256	33.46
12	125.8	89.2	36.6	614	336	278	36.19
12	130.9	95.2	35.7	337	59	278	36.19
13	65.1	25.8	39.2	357	55	302	39.32
13	80.8	41.8	39.0	379	77	302	39.47
14	107.5	65.1	41.9	458	133	325	42.31
14	56.7	14.2	42.5	391	68	323	42.05
15	52.4	7.5	44.9	415	67	348	45.31
15	110.9	66.3	44.6	607	260	347	45.35
16	100.6	52.4	48.2	468	96	372	48.43
16	65.0	16.7	48.3	552	181	371	48.30
17	52.1	.6	51.5	475	81	394	51.30
17	149.5	98.2	51.3	544	152	392	51.23
18	106.9	52.1	54.8	474	56	418	54.42
18	119.2	65.0	54.2	507	90	417	54.29
19	64.3	6.9	57.4	514	73	441	57.42
19	127.9	70.0	57.9	534	94	440	57.51
20	124.9	64.3	60.6	533	69	464	60.41
20	116.7	56.7	60.0	581	119	462	60.15
21	88.4	24.9	63.5	605	119	486	63.28
21	95.2	31.1	64.1	586	98	488	63.78
22	154.5	88.4	66.1	568	59	509	66.27
22	114.2	47.9	66.3	532	22	510	66.40
23	123.5	54.5	69.0	593	59	534	69.53
23	139.0	69.1	69.9	748	213	535	69.92
24	96.6	23.5	73.1	628	71	557	72.52
24	147.9	75.7	72.2	599	43	556	72.39
25	171.8	96.6	75.2	604	24	580	75.52
25	170.0	95.2	74.8	690	111	579	75.67
26	150.0	71.8	78.2	631	28	603	78.51
26	75.7	96.8	78.9	607	3	604	78.64
27	132.0	50.0	82.0	654	28	626	81.50
27	131.1	49.5	81.6	770	145	625	81.69

Parkinson-Cowan Meter				Tissot			
Pumps	End	Start	Change (liters)	End	Start	Change (mm)	Volume (liters)
28	116.8	32.0	84.8	658	9	649	84.50
28	96.8	12.1	84.7	665	17	648	84.37
29	104.3	16.8	87.5	686	15	671	87.36
29	98.7	10.9	87.8	673	1	672	87.83
30	95.2	4.3	90.9	705	9	696	90.62
30	158.3	67.7	90.6	706	9	697	90.75

Comparison of Gas Meter Volumes Versus Tissot Volumes.

Trial	Number of Pumps	Tissot (liters)	Gasometer (liters)
1	01	2.99	3.0
2	01	3.01	2.8
3	02	6.12	6.5
4	02	5.99	6.5
5	03	9.11	9.3
6	03	9.15	8.9
7	04	12.11	11.5
8	04	11.98	11.5
9	05	15.10	15.7
10	05	15.16	15.6
11	06	18.10	17.6
12	06	17.97	18.6
13	07	21.22	21.5
14	07	21.43	21.1
15	08	24.08	24.1
16	08	24.08	23.7
17	09	27.21	27.3
18	09	27.32	27.4
19	10	29.95	30.3
20	10	30.08	30.3
21	11	33.33	32.9
22	11	33.46	33.5
23	12	36.19	36.6
24	12	36.19	35.7
25	13	39.32	39.2
26	13	39.47	39.0
27	14	42.31	41.9
28	14	42.05	42.5
29	15	45.31	44.9
30	15	45.35	44.6
31	16	48.43	48.2
32	16	48.30	48.3
33	17	51.30	51.5
34	17	51.23	51.3
35	18	54.42	54.8
36	18	54.29	54.2
37	19	57.42	57.4
38	19	57.51	57.9
39	20	60.41	60.6
40	20	60.15	60.0
41	21	63.28	63.5
42	21	63.78	64.1
43	22	66.27	66.1

Trial	Number of Pumps	Tissot (liters)	Gasometer (liters)
44	22	66.40	66.3
45	23	69.53	69.0
46	23	69.92	69.9
47	24	72.52	73.1
48	24	72.39	72.2
49	25	75.52	75.2
50	25	75.67	74.8
51	26	78.51	78.2
52	26	78.64	78.9
53	27	81.50	82.0
54	27	81.69	81.6
55	28	84.50	84.8
56	28	84.37	84.7
57	29	87.36	87.5
58	29	87.83	87.8
59	30	90.62	90.9
60	30	90.75	90.6

APPENDIX C

MICRO-SCHOLANDER GAS ANALYZER PROCEDURE

MICRO-SCHOLANDER GAS ANALYZER PROCEDURE
(Modified from Scholander, 1947)

The following steps give the sequence for proper analysis of O_2 and CO_2 percentages in a respiratory gas sample.

Preliminaries - "Washing out the Apparatus"

1. Check the level of the water bath. It should be up to the neck of the compensating vessel. Distilled or deionized water can be used to fill or refill the water bath.

2. Remove any acid rinsing solution from the acid rinsing chamber. Rinse the acid rinsing chamber with deionized water. Mix the bottle containing the acid rinsing solution well and add the solution to the acid rinsing chamber. Put the chamber back in the water bath.

3. With the stop-cock in Position III (Figure 2), remove the CO_2 absorber. Remove the O_2 absorber next. The same syringe may be used with different needles.

4. Add new CO_2 reagent by pouring CO_2 absorber into a clean syringe (try not to produce bubbles). Make a puddle of the CO_2 absorber on top of the stopper and inject CO_2 absorber until the side arm for CO_2 is 3/4 full with the CO_2 absorber.

Add new O_2 absorber by pouring O_2 absorber into a clean syringe. Make a puddle of the O_2 absorber on the top of the stopper and inject O_2 absorber to until the side arm for O_2 is 3/4 full with the O_2 absorber.

5. With the stop-cock in Position III, add acid rinsing solution, by way of a rubber ball pipette, to the compensating chamber to about 3/4 full.

With the mercury leveling bulb, draw the acid rinsing solution down just below the side arm openings. Move the acid rinsing solution up and down, past the side arm openings, two to four times, and then back up the thermobarometer.

Move the stop-cock to the lock position (blue dot on the side positioned at about "two-o'clock"), suction, and add another batch of acid rinsing solution. Rinse again, and allow the acid rinsing solution to stand to moisten the Piccolite in the reaction chamber for about 15 minutes.

6. With the stop-cock in Position III, move the acid rinsing solution in the reaction chamber with the mercury leveling bulb, through the thermobarometer. Suction this and add acid rinsing solution to the thermobarometer so it is half full.

Adjust the mercury to the top of the capillary with the wooden dowel connected to the micrometer.

Transfer of gas sample

1. Expired gas from a meteorological balloon is transferred by way of a Bailey bottle for testing.

2. From a syringe fitted with a gauge No. 24 needle, squirt a large drop of mercury into a transfer pipette. Shake the drop of mercury to the bottom of the transfer pipette, seal the rubber pipette tip over the opening of the Bailey bottle. Allow the gas to flow through the pipette until a sufficient sample is obtained.

3. When the pipette is removed from the Bailey bottle, the mercury starts to fall slowly down the pipette. Before the drop has fallen too far, seat/seal the rubber tip of the pipette on through the acid rinsing solution, into the top of the capillary in the thermobarometer or

compensation chamber.

4. With the stop-cock in Position I, screw the gas meniscus down until it bisects the mark on the capillary, by adjusting the wooden dowel on the micrometer.

5. With the stop-cock now in Position II, zero the micrometer by actually adjusting it to .05 of the smallest division past zero. This adjustment is necessary due to the elasticity of the rubber stoppers.

6. Turn the stop-cock back to Position I and screw the micrometer gently and evenly out to about 12 to 15 on the scale. This number varies on the size of the sample and size of the reaction chamber.

7. Remove the transfer pipette from the acid rinsing chamber, and allow a small amount of the acid rinsing solution (about 2mm) to enter the capillary.

8. Aspirate out all the rest of the acid and rinsing solution in the compensatory chamber.

9. Screw the acid rinsing indicator drop down until the lower meniscus of the drop coincides roughly with the mark on the capillary.

10. Dry the opening of the thermobarometer with a cotton swab, and then insert the stop-cock in the opening of the thermobarometer.

11. With the stop-cock open, move the indicator drop up and down in the capillary to pick up acid adhering to it.

12. Readjust the lower meniscus of the indicator drop by moving the micrometer until it touches the mark on the capillary. Take a reading off the micrometer.

13. Close the stop-cock and repeat the procedure until the micrometer reading is constant. Record this reading as M_1.

Absorbing CO_2 and O_2

1. Tilt the apparatus cautiously downward on the CO_2-absorbent side (left), admitting a small amount of the absorbent to enter the reaction chamber. At the same time, adjust the micrometer (by way of the wooden dowel) to compensate for the downward movement of the indicator drop in the capillary caused by the CO_2 absorption.

2. Start the vibrator motor to facilitate the absorption of CO_2. Keep adjusting the wooden dowel so the indicator drop does not fall below the reaction chamber.

3. When the indicator drop is stationary, stop the vibrator motor, and readjust the lower meniscus to the mark on the capillary, in the reaction chamber. Record the reading on the micrometer as M_2.

4. Tilt the O_2-absorbent side (right) down, admitting oxygen absorbent so that the mercury is covered with about 1mm of the absorbent.

5. Start the vibrator motor, at the same time screwing the micrometer via the wooden dowel. This is to compensate for the downward movement of the indicator drop due to the O_2 absorption.

6. When the indicator drop is stationary in the capillary, record the reading on the meniscus as M_3.

7. Open the stop-cock in the compensating chamber to room air.

8. Adjust the micrometer until the meniscus of the absorbing solution reaches the mark on the capillary. This should make the micrometer reading zero within ± 0.5 of the smallest division.

Calculations

CO_2 - cc per 100cc, original sample, dry = $\frac{M_1-M_2}{M_1} \times 100$

O_2 - cc per 100cc, original sample, dry = $\frac{M_2-M_3}{M_1} \times 100$

Results are satisfactory when duplicate analyses for CO_2 and O_2 agree within .03 percent. At least two analyses are done on a sample of gas and if the two analyses are within the criterion the average of the two readings is the final value.

Preparation for following analyses

1. Turn the stop-cock to Position III (blue dot up) and aspirate off the absorbing solutions.

2. Repeat the sequence of steps beginning with #5 under "Preliminaries" through this step for each analysis.

Cleaning

1. Rinse the reaction chamber twice with the acid rinsing solution; aspirating out the solutions between each rinse.

2. Rinse the reaction chamber twice with deionized water; aspirate out.

3. With the stop-cock in Position III, move the mercury by way of the mercury leveling bulb, to about the halfway mark in the reaction chamber.

4. Turn the stop-cock to Position I.

5. Cover the machine.

Labeled portions of the diagram in Figure 5.

A - Compensating chamber or thermobarometer

B - Reaction chamber

C - Side arm for carbon dioxide absorber

D - Side arm for oxygen absorber

E & F - Solid vaccine bottle stoppers

G - Receptacle for stop-cock S-1

H - Micrometer burette; S-2 stop-cock for micrometer burette

I - Mercury leveling bulb

J - Handle for tilting the apparatus

K - Chamber for storing acid rinsing solution

L - Pipette for acid rinsing solution

* The heavily drawn lower end of the capillary at letter B indicates where the capillary is surface-ground, which is coated with a substance called Piccolite.

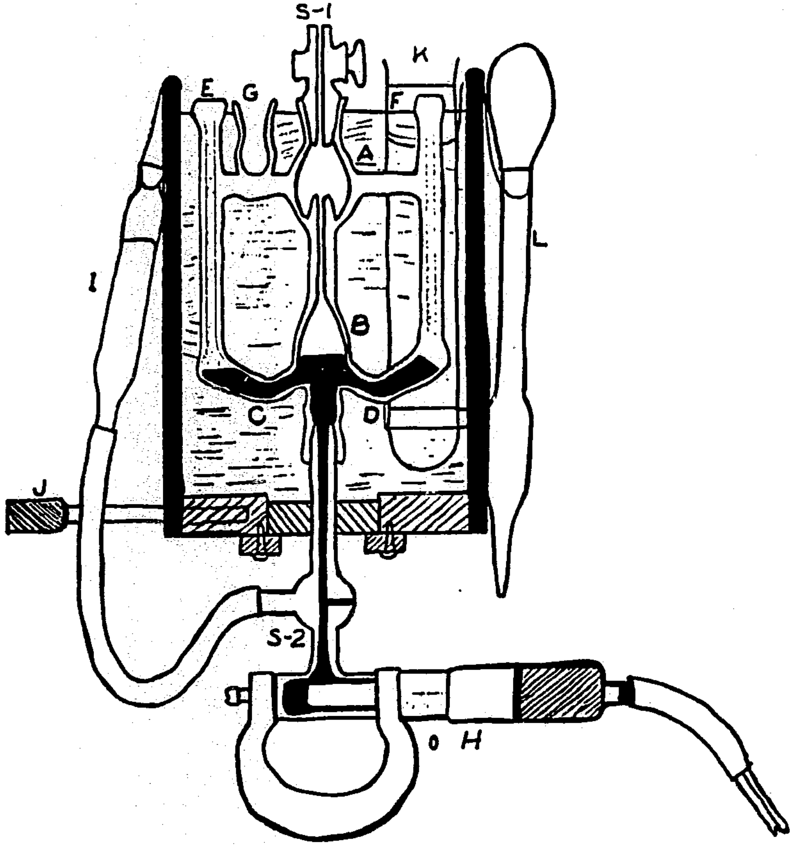

Figure 5. Scholander Gas Analyzer Apparatus for Accurate Estimation of Respiratory Gases in 0.5 cc. Samples (Scholander, 1947 p. 237).

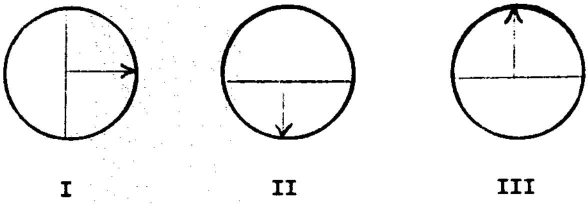

Figure 6. S-2 Stop-Cock Positions.

I - Micrometer to the reaction chamber (arrow to right)

II - Micrometer to the mercury leveling bulb (arrow down)

III - Mercury leveling bulb to the reaction chamber (arrow up)

APPENDIX D

METABOLIC CALCUATIONS

METABOLIC CALCULATIONS

By definition, oxygen consumption is the difference between the inspired and expired flows of oxygen:

$$VO_2 = (VI_{STPD} \times FIO_2) - (VE_{STPD} \times FEO_2)$$

in which VO_2 is oxygen consumption (l·min)
VI_{STPD} is inspired flow (l·min) at STPD conditions
VE_{STPD} is expired flow (l·min) at STPD conditions
FIO_2 is the volume fraction of oxygen in inspired gas
FEO_2 is the volume fraction of oxygen in expired gas

The volume of expired gas was collected for one minute so:

$$V_{ATPS} = \frac{\text{Volume (ATPS)}}{\text{minute}}$$

The expired gas volume is measured at its actual ambient temperature and pressure, saturated with water vapor (ATPS), but is corrected to body temperature and pressure saturated with water vapor (BTPS) as follows:

$$V_{BTPS} = V_{ATPS} \left[\frac{P_B - PH_2O}{P_B - 47\text{mm Hg}}\right] \left[\frac{310}{273 + T}\right]$$

in which V_{BTPS} is the volume of gas at BTPS
V_{ATPS} is the volume of gas at ATPS
P_B is the barometric pressure (in mmHg)
T is the temperature at which the expired gas is measured (°C)
PH_2O is the partial pressure for gas that is 100% saturated with water vapor at that temperature

Since volumes of gases exchanged in metabolic measurements are expressed as the volume that that gas would occupy at standard temperature (0°C) and pressure (760 mm Hg) and as a dry gas (STPD) volumes expressed as BTPS are converted to a volume at STPD as follows:

$$V_{STPD} = V_{ATPS} \left(\frac{273}{273 + T}\right) \left(\frac{P_B - PH_2O}{760}\right)$$

The inspired volume is calculated from the expired volume by the Haldane transform (Wilmore & Costill, 1973):

$$VI_{STPD} = VE_{STPD} \times \frac{FEN_2}{FIN_2}$$

in which FEN_2 is the expired nitrogen fraction (by volume)

FIN_2 is the inspired nitrogen fraction (by volume)

According to McArdle et al. (1986) the FEN_2 is calculated:

$$FEN_2 = 1 - (FEO_2 + FECO_2)$$

in which FEO_2 is the expired O_2 fraction

$FECO_2$ is the expired CO_2 fraction.

From the above calculations, the following sequence is used to calculate oxygen consumption given $FIO_2 = .2093$ and $FICO_2 = .0003$:

Step 1 $FIN_2 = 1 - (FIO_2 + FICO_2)$

2 $FEN_2 = 1 - (FEO_2 + FECO_2)$

3 $V_{ATPS} = \frac{\text{Volume}}{\text{Time in seconds}} \times \frac{60\text{ sec}}{\text{min}}$

4 $VE_{STPD} = V_{ATPS} \left[\frac{273}{273 + T}\right] \left[\frac{P_B - PH_2O}{760}\right]$

5 $VI_{STPD} = VE_{STPD} \times \frac{FEN_2}{FIN_2}$

6 $VO_2 = (VI_{STPD} \times FIO_2) - (VE_{STPD} \times FEO_2)$

From the same basic measurements carbon dioxide production, minute volume (BTPS), and respiratory exchange ratio can also be determined:

$$VO_2\ ml\cdot kg^{-1}\cdot min^{-1} = \frac{VO_2 \times 1000}{\text{Subject's weight in kg}}$$

$$VCO_2 = VE_{STPD}\ (FECO_2 - FICO_2)$$

$$VE_{BTPS} = VE_{STPD} \left(\frac{760}{P_B - 47}\right)\left(\frac{310}{273}\right) = VE_{STPD}\ \frac{863}{P_B - 47}$$

$$RER = VCO_2\ /\ VO_2$$

APPENDIX E

TREADMILL PROTOCOL

TREADMILL PROTOCOL

The University of Wisconsin-La Crosse
La Crosse, Wisconsin

A VALIDATION STUDY OF THE Q-PLEX I CARDIOPULMONARY EXERCISE SYSTEM

(William G. Davey)

Stage	MPH	% Grade	Start Time	End Time
1	3.5	10	0 min	4:59
2	8.0	0	5 min	8:59
3	8.0	3	9 min	11:59
4	8.0	6	12 min	14:59
5	8.0	9	15 min	17:59
6	8.0	12	18 min	20:59
7	8.0	15	21 min	23:59

APPENDIX F

MEASUREMENT OF VE ON INSPIRED SIDE VERSUS Q-PLEX VE

MEASUREMENT OF VE ON INSPIRED SIDE VERSUS THE Q-PLEX

Comparison of Volume Measurement of Parkinson-Cowan Meter to the Q-Plex. VE(BTPS) for the Parkinson-Cowan Meter is based on the VI(ATPS) corrected to VE(BTPS).

Subject	Time (min)	Speed (mph)	Grade (%)	PC-Meter VE(BTPS)	Q-Plex VE(BTPS)
1	5	3.5	10	44.7	48.4
	9	8	0	77.2	84.5
	12	8	3	95.8	104.0
	15	8	6	120.3	132.6
2	2	3.5	10	37.4	38.5
	3	3.5	10	36.8	38.6
	4	3.5	10	38.1	40.2
	5	3.5	10	40.8	42.6
	6	8	0	51.9	54.8
	7	8	0	58.4	64.2
	8	8	0	65.2	69.5
	9	8	0	66.1	70.5
	10	8	3	65.3	71.3
	11	8	3	74.5	79.1
	12	8	3	69.6	76.0
	13	8	6	78.7	85.3
	14	8	6	81.6	91.4
	15	8	6	87.0	94.5
	16	8	9	94.6	101.5
	17	8	9	102.1	112.1
3	2	3.5	10	51.2	52.1
	3	3.5	10	50.0	58.7
	4	3.5	10	57.5	61.6
	5	3.5	10	55.4	61.0
	6	8	0	65.3	71.7
	7	8	0	78.9	83.7
	8	8	0	86.4	93.1
	9	8	0	91.2	98.4
	10	8	3	95.2	103.5
	11	8	3	108.2	115.4
	12	8	3	112.2	124.8
	13	8	6	121.7	132.4
	14	8	6	133.6	146.0
	15	8	6	142.6	155.5
	16	8	9	153.5	170.1
	17	8	9	162.6	180.5

Subject	Time (min)	Speed (mph)	Grade (%)	PC-Meter VE(BTPS)	Q-Plex VE(BTPS)
4	2	8	0	39.4	43.0
	3	8	0	42.8	45.3
	4	8	0	45.6	46.6
	5	9	0	48.2	51.0
	6	9	0	47.1	50.7
	7	9	0	56.1	59.1
	8	9	0	55.4	57.8
	9	9	0	55.8	59.5
	10	9	0	57.0	60.1
	11	10	0	61.5	64.6
	12	10	0	69.2	72.7
	13	10	2.5	66.5	71.3
	14	10	2.5	74.3	77.8
	15	10	5	78.9	84.2
	16	10	7.5	91.7	96.1
	17	10	10	106.8	112.5

Ambient Conditions for VI (ATPS) Measurements in Table 5.
(Pb = barometric pressure, RH = relative humidity)

Subject	Pb (mm Hg)	Temperature (°C)	PH_2O max (mm Hg)	RH (%)	BTPS Factor
1	751	24.5	23.06	53	1.093
2	741	21.1	18.77	56	1.109
3	739	20.1	17.64	63	1.113
4	744	22.2	20.07	57	1.104

APPENDIX G

SUBJECTS' RAW DATA

Comparison of Gas Exchange Data: Q-Plex vs Manual Determination.
QPX = Q-Plex, MAN = Manual.

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	37.0	15.96	4.26	26.8	1.25	0.82
				QPX	40.5	15.87	4.41	28.9	1.41	0.86
9	8.0	0	46.4	MAN	65.3	16.16	4.41	44.6	2.29	0.90
				QPX	69.9	16.02	4.46	48.0	2.48	0.90
12	8.0	3	52.2	MAN	77.2	15.97	4.65	54.3	2.85	0.92
				QPX	81.9	15.97	4.66	56.3	3.03	0.94
15	8.0	6	58.0	MAN	92.7	16.22	4.63	61.6	3.41	0.97
				QPX	97.2	16.20	4.63	62.9	3.57	0.99
18	8.0	9	63.7	MAN	110.3	16.55	4.57	67.0	4.00	1.04
				QPX	117.9	16.52	4.55	69.9	4.25	1.06
5	3.5	10	29.8	MAN	53.4	15.14	4.90	36.3	2.09	0.81
				QPX	55.2	15.48	4.79	34.1	2.11	0.86
9	8.0	0	46.4	MAN	88.0	15.59	4.63	54.8	3.26	0.83
				QPX	94.3	15.79	4.55	54.9	3.42	0.87
12	8.0	3	52.2	MAN	90.3	15.74	4.70	54.1	3.39	0.87
				QPX	99.5	15.71	4.72	58.4	3.74	0.89
15	8.0	6	58.0	MAN	117.4	16.20	4.65	62.9	4.37	0.97
				QPX	128.7	16.21	4.66	66.6	4.77	1.00
18	8.0	9	63.7	MAN	157.1	16.98	4.15	69.0	5.21	1.05
				QPX	162.1	16.97	4.16	68.8	5.36	1.09
5	3.5	10	29.8	MAN	55.0	15.71	4.47	27.0	1.96	0.82
				QPX	61.4	15.55	4.53	30.3	2.22	0.82
9	8.0	0	46.4	MAN	126.8	16.78	3.96	48.3	4.00	0.93
				QPX	136.5	16.84	3.91	49.1	4.25	0.97
12	8.0	3	52.2	MAN	145.8	16.99	3.92	52.2	4.55	0.98
				QPX	159.7	16.95	3.85	55.8	4.91	0.99
15	8.0	6	58.0	MAN	186.3	17.49	3.53	57.8	5.24	1.02
				QPX	206.8	17.44	3.56	62.1	5.87	1.06

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	41.5	16.13	4.30	28.3	1.45	0.86
				QPX	44.6	15.92	4.44	31.1	1.60	0.87
9	8.0	0	46.4	MAN	59.5	15.94	4.36	42.4	2.11	0.84
				QPX	63.0	15.93	4.34	44.0	2.20	0.84
12	8.0	3	52.2	MAN	68.3	16.23	4.22	45.6	2.34	0.86
				QPX	74.5	15.92	4.49	51.7	2.69	0.88
15	8.0	6	57.8	MAN	97.3	16.63	4.15	58.4	3.28	0.95
				QPX	101.7	16.66	4.11	58.9	3.37	0.96
18	8.0	9	63.8	MAN	115.1	16.83	4.19	64.8	3.91	1.02
				QPX	122.0	16.82	4.23	67.0	4.16	1.05
5	3.5	10	29.8	MAN	41.8	15.28	5.07	28.5	1.70	0.87
				QPX	45.2	14.95	5.35	32.0	1.95	0.89
9	8.0	0	46.4	MAN	53.0	14.85	5.49	38.8	2.34	0.87
				QPX	53.0	14.30	5.88	41.5	2.51	0.87
12	8.0	3	52.2	MAN	73.1	15.42	5.34	47.7	3.13	0.95
				QPX	76.3	15.36	5.38	48.9	3.29	0.98
15	8.0	6	57.8	MAN	72.6	15.66	5.33	44.8	3.11	1.01
				QPX	78.8	15.38	5.56	50.0	3.52	1.02
5	3.5	10	29.8	MAN	44.6	15.00	4.91	27.8	1.77	0.79
				QPX	46.9	15.29	4.84	27.0	1.83	0.84
9	8.0	0	46.4	MAN	77.3	15.48	4.74	43.9	2.95	0.83
				QPX	81.8	15.42	4.85	45.7	3.19	0.87
12	8.0	3	52.2	MAN	106.8	15.70	4.79	57.6	4.12	0.89
				QPX	101.6	15.69	4.81	53.2	3.94	0.92
15	8.0	6	58.0	MAN	118.3	16.01	4.82	58.9	4.59	0.96
				QPX	125.4	15.96	4.85	61.3	4.89	0.99
18	8.0	9	63.7	MAN	158.6	16.68	4.47	67.0	5.71	1.05
				QPX	167.0	16.66	4.46	68.6	5.98	1.08

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	51.4	15.83	4.80	27.5	1.97	0.92
				QPX	53.2	15.60	5.01	29.1	2.13	0.94
9	8.0	0	46.4	MAN	91.7	16.80	4.06	39.3	2.97	0.97
				QPX	97.6	16.68	4.15	41.9	3.23	0.99
12	8.0	3	52.2	MAN	114.1	16.92	4.11	47.0	3.74	1.02
				QPX	121.3	16.87	4.17	48.9	4.03	1.06
15	8.0	6	57.8	MAN	131.4	16.94	4.32	53.0	4.52	1.09
				QPX	140.6	16.96	4.32	54.5	4.84	1.14
5	3.5	10	29.8	MAN	64.9	16.29	4.22	35.9	2.22	0.88
				QPX	69.5	16.64	4.03	34.2	2.26	0.94
9	8.0	0	46.4	MAN	87.2	16.51	4.09	45.8	2.89	0.90
				QPX	96.1	16.53	4.06	48.9	3.16	0.92
12	8.0	3	52.2	MAN	88.8	16.11	4.47	50.8	3.22	0.90
				QPX	96.3	16.07	4.46	54.3	3.48	0.91
15	8.0	6	57.8	MAN	121.1	16.68	4.31	59.8	4.23	1.01
				QPX	132.0	16.59	4.33	64.7	4.64	1.02
5	3.5	10	29.8	MAN						
				QPX						
9	8.0	0	46.4	MAN	79.6	15.49	5.11	48.3	3.21	0.92
				QPX	84.5	15.50	5.15	49.9	3.44	0.95
12	8.0	3	52.2	MAN	103.3	16.02	4.92	55.7	4.01	0.99
				QPX	109.3	15.98	4.90	57.9	4.23	1.01
15	8.0	6	58.0	MAN	126.4	16.53	4.52	60.7	4.51	1.02
				QPX	136.0	16.51	4.56	63.3	4.88	1.06
18	8.0	9	63.7	MAN	183.5	17.42	3.86	69.0	5.58	1.12
				QPX	196.0	17.47	3.83	69.4	5.91	1.17

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	47.3	15.84	4.63	27.7	1.77	0.88
				QPX	49.3	15.66	4.72	29.3	1.88	0.88
9	8.0	0	46.4	MAN	77.9	16.03	4.58	43.6	2.88	0.91
				QPX	82.8	15.98	4.57	45.7	3.05	0.92
12	8.0	3	52.2	MAN	97.7	16.30	4.43	51.4	3.49	0.94
				QPX	105.3	16.33	4.45	53.3	3.78	0.98
15	8.0	6	58.0	MAN	128.2	16.96	4.27	56.0	4.41	1.09
				QPX	140.0	16.93	4.18	60.0	4.72	1.08
5	3.5	10	29.8	MAN	62.0	15.93	4.53	29.2	2.28	0.87
				QPX	65.6	15.92	4.49	30.0	2.40	0.89
9	8.0	0	46.4	MAN	84.6	15.92	4.66	39.6	3.20	0.90
				QPX	87.8	15.85	4.62	40.7	3.30	0.91
12	8.0	3	52.2	MAN	99.9	15.93	4.79	46.4	3.89	0.94
				QPX	105.0	15.91	4.80	47.4	4.10	0.97
15	8.0	6	58.0	MAN	124.3	16.16	4.88	54.1	4.93	1.02
				QPX	130.2	16.12	4.87	55.3	5.16	1.04
18	8.0	9	63.7	MAN	136.2	16.64	4.72	52.3	5.22	1.12
				QPX	138.6	16.61	4.69	51.9	5.30	1.14
5	3.5	10	29.8	MAN	42.1	15.54	4.81	29.2	1.63	0.86
				QPX	45.4	15.46	4.89	31.2	1.79	0.88
9	8.0	0	46.4	MAN	59.3	15.73	4.80	39.4	2.29	0.90
				QPX	63.6	15.56	4.74	43.0	2.43	0.87
12	8.0	3	52.2	MAN	69.1	15.44	4.91	49.7	2.49	0.77
				QPX	73.6	15.38	4.92	51.5	2.92	0.87
15	8.0	6	58.0	MAN	84.8	15.58	5.02	57.7	3.42	0.91
				QPX	91.2	15.54	5.04	61.1	3.70	0.93
18	8.0	9	63.7	MAN	105.9	15.89	5.09	66.6	4.33	1.00
				QPX	112.8	15.88	5.06	69.4	4.59	1.02
21	8.0	12	69.5	MAN	126.3	16.39	4.91	70.2	4.98	1.09
				QPX	137.9	16.35	4.85	75.4	5.38	1.10

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	45.9	15.73	4.59	30.5	1.68	0.85
				QPX	49.1	15.55	4.75	32.7	1.86	0.88
9	8.0	0	46.4	MAN	70.7	16.30	4.18	41.6	2.35	0.87
				QPX	76.9	16.15	4.32	45.1	2.64	0.90
12	8.0	3	52.2	MAN	82.4	16.06	4.45	50.8	2.91	0.88
				QPX	88.5	16.02	4.47	53.2	3.15	0.91
15	8.0	6	58.0	MAN	105.3	16.45	4.31	59.0	3.61	0.94
				QPX	115.0	16.37	4.40	63.1	4.03	0.98
18	8.0	9	63.7	MAN	133.6	16.80	4.22	67.9	4.48	1.02
				QPX	142.8	16.77	4.22	70.2	4.80	1.05
5	3.5	10	29.8	MAN	58.1	16.01	4.40	25.6	2.02	0.86
				QPX	60.1	15.56	4.60	28.5	2.18	0.84
9	8.0	0	46.4	MAN	106.1	16.20	4.33	44.8	3.63	0.89
				QPX	112.6	16.08	4.36	47.7	3.89	0.89
12	8.0	3	52.2	MAN	131.0	16.30	4.41	53.6	4.57	0.93
				QPX	138.5	16.30	4.38	55.3	4.80	0.95
15	8.0	6	58.0	MAN	170.9	16.92	4.05	59.7	5.47	1.00
				QPX	177.6	16.88	4.05	60.7	5.68	1.02
5	3.5	10	29.8	MAN	50.2	15.89	4.51	28.7	1.79	0.86
				QPX	54.9	15.87	4.53	30.3	1.97	0.90
9	8.0	0	46.4	MAN	72.6	15.87	4.58	41.5	2.63	0.87
				QPX	76.8	15.79	4.59	43.1	2.79	0.89
12	8.0	3	52.2	MAN	84.2	15.92	4.51	47.8	3.01	0.87
				QPX	90.2	15.87	4.60	49.6	3.28	0.91
15	8.0	6	58.0	MAN	102.3	16.07	4.63	55.6	3.76	0.93
				QPX	108.8	16.08	4.61	56.7	3.97	0.96
18	8.0	9	63.7	MAN	132.1	16.51	4.50	64.1	4.71	1.01
				QPX	142.3	16.50	4.51	66.3	5.08	1.06
21	8.0	12	69.5	MAN	172.4	17.13	4.12	69.6	5.62	1.10
				QPX	184.0	17.07	4.12	73.1	6.00	1.13

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	49.7	15.11	5.20	31.9	2.08	0.86
				QPX	52.1	15.05	5.41	32.4	2.27	0.93
9	8.0	0	46.4	MAN	68.0	15.56	5.10	39.7	2.79	0.93
				QPX	71.8	15.44	5.18	41.4	3.00	0.96
12	8.0	3	52.2	MAN	93.1	15.88	4.89	50.9	3.66	0.95
				QPX	98.9	16.01	4.82	50.3	3.84	1.01
15	8.0	6	58.0	MAN	112.5	16.27	4.88	55.6	4.42	1.05
				QPX	119.4	16.22	4.86	57.2	4.67	1.08
5	3.5	10	29.8	MAN	53.7	15.76	4.58	29.9	1.99	0.85
				QPX	57.5	15.79	4.66	30.9	2.17	0.90
9	8.0	0	46.4	MAN	89.6	16.00	4.62	47.0	3.35	0.91
				QPX	94.9	15.95	4.62	49.0	3.55	0.93
12	8.0	3	52.2	MAN	106.7	16.21	4.56	53.2	3.94	0.95
				QPX	115.9	16.17	4.59	56.6	4.30	0.97
5	3.5	10	29.8	MAN	41.7	15.52	4.65	30.9	1.57	0.82
				QPX	45.2	15.60	4.77	31.9	1.75	0.88
9	8.0	0	46.4	MAN	61.2	15.60	4.66	44.5	2.32	0.84
				QPX	67.0	15.50	4.68	48.6	2.55	0.84
12	8.0	3	52.2	MAN	72.5	15.41	4.91	54.4	2.89	0.86
				QPX	76.8	15.44	4.88	55.9	3.05	0.88
15	8.0	6	58.0	MAN	84.5	15.64	4.99	59.9	3.43	0.92
				QPX	91.0	15.65	4.97	62.7	3.67	0.94
18	8.0	9	63.7	MAN	103.6	15.72	5.16	71.4	4.34	0.98
				QPX	110.9	15.81	5.10	73.0	4.59	1.01
21	8.0	12	69.5	MAN	141.0	16.42	4.83	82.4	5.53	1.08
				QPX	139.7	16.51	4.72	77.3	5.35	1.11

Test Time	MPH	%	VO2 Est.	MAN QPX	VE BTPS	%O2	%CO2	VO2 /Kg	VCO2	RER
5	3.5	10	29.8	MAN	48.2	15.92	4.39	29.7	1.69	0.84
				QPX	51.6	15.76	4.63	31.3	1.92	0.90
9	8.0	0	46.4	MAN	72.3	15.76	4.67	45.6	2.70	0.87
				QPX	78.1	15.85	4.68	46.2	2.93	0.93
12	8.0	3	52.2	MAN	81.7	15.66	4.89	52.2	3.20	0.90
				QPX	88.1	15.63	4.90	54.4	3.46	0.94
15	8.0	6	58.0	MAN	107.6	16.16	4.69	61.3	4.04	0.97
				QPX	114.5	16.15	4.66	62.5	4.26	1.00
18	8.0	9	63.7	MAN	134.4	16.61	4.52	68.2	4.86	1.05
				QPX	139.8	16.58	4.49	68.2	5.02	1.08
5	3.5	10	29.8	MAN	47.4	15.66	5.11	26.6	1.93	0.95
				QPX	53.3	15.47	5.21	30.2	2.22	0.96
9	8.0	0	46.4	MAN	78.1	16.01	4.66	41.2	2.90	0.92
				QPX	82.9	15.81	4.73	44.2	3.12	0.93
12	8.0	3	52.2	MAN	86.9	15.54	5.11	50.2	3.54	0.93
				QPX	92.9	15.50	5.10	52.3	3.76	0.94
15	8.0	6	58.0	MAN	106.1	15.70	5.16	58.8	4.37	0.97
				QPX	111.5	15.67	5.17	60.2	4.58	1.00
18	8.0	9	63.7	MAN	123.2	15.87	5.29	65.1	5.20	1.05
				QPX	127.4	15.86	5.29	65.1	5.37	1.08