A COMPARISON OF METABOLIC MEASUREMENT TECHNIQUES

by

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Chapter 1

INTRODUCTION

Metabolic measurements are commonplace in most exercise physiology laboratories. Oxygen consumption ($\dot{V}O_2$) respiratory quotient (RQ) oxygen cost and caloric cost are parameters that can be readily assessed. Reliable research can be conducted provided the ability to make accurate metabolic measurements is available. Accurate collection of expired air samples is vital to the reliability of oxygen consumption determinations. Traditional methods of obtaining expired air samples included the Douglas Bag and large spirometers, such as Tissot Tanks. The Douglas Bag is more mobile than the Tissot Tank which is physically large and heavy.

The Douglas Bag is a 50 or 100 liter canvas bag with a rubberized inner lining. Subjects' exhaled air is directed into the bag by the use of a mouthpiece incorporating a one-way valve. In a field setting, the bag is carried on the subject's back. In the laboratory, the bag is suspended from specially devised structures. The Douglas Bag is adequate for field use, however, it has proven to be rather cumbersome in a laboratory setting.

The Tissot Tank is another method of determining respiratory function and obtaining expired air samples. The Tissot Tank, a counter balanced, water sealed bell spirometer provides a very accurate measure of gas volume (7). However, it is very large, made of metal and very heavy when filled with water. Also, smaller gas samples must be drawn off the bell into another bag or the Tissot must be connected directly

to the gas analyzer so oxygen and carbon dioxide levels can be determined. The Tissot is very accurate; however, its size and weight limit its mobility and field use.

Another method has recently been utilized to collect gas samples. That is the Mini Bag (38). A small, 700 cc to 1000 cc metalized plastic bag with a stop cock inserted in one end serves as the sample bag. The procedure of this technique involves a subject breathing through a one-way valve. Connected with tubing to the air import chamber of the valve is a gas meter that measures inhaled air. A hose leads from the valve's export chamber to an air mixing chamber. The air mixing chamber consists of an expanded cylinder with a one-way valve over the air exit and a port in the center from which gas samples can be drawn for the purpose of analysis. Expired air is drawn from the mixing chamber with a vacuum pump and the Mini Bag is filled with expired air from the pump. The Mini Bag is usually filled with intermittent bursts of air of designated time periods to produce a representative sample.

The Mini Bag is probably the simplest of all three methods to administer in a laboratory situation. Air volumes are determined by reading the gas meter as the subject respirates; as opposed to the Douglas Bags which require the air to be forced back through the gas meter after collection in order to determine air volumes. This leaves only the correction for standard temperature, pressure and dry remaining to be determined. Because of the Mini Bag's dimensions, it serves as the sample bag, therefore, no gas transfer is required. The much smaller physical size of these bags makes them much easier to handle.

Because the Mini Bag is perhaps more easily administered, it becomes logical to question its consistency as a gas collection technique.

Does the fact that gas samples are drawn intermittently over a given interval of time prove it more or less consistent? Does a difference in the sample collection duration render it undependable? Does either the Douglas Bag or the Tissot Tank offer a statistically more trustworthy method of gas collection?

Research comparing these different methods is sparse. The need exists to study and/or compare the consistency among these different methods of metabolic determination.

PURPOSE

It was the purpose of this study to examine three techniques of gas collection. More specifically, comparisons of oxygen uptake in liters per minute and milliliters per kilogram per minute, ventilation, oxygen percent, carbon dioxide percent, and respiratory quotient were made among the three techniques and among different collection durations in order to determine if statistical differences existed.

LIMITATIONS

It is recognized that certain limitations were inherent to this study. In lieu of original Douglas Bags, rubber weather balloons were utilized. Because of subject availability, some subjects provided more data than others; however, all provided a minimum of five sets of data each.

Because the amount of air ventilated during a 120 second interval by some subjects exceeded the 120 liter capacity of the Tissot Tank used, a 120 second duration sample could not be obtained with the Tissot Tank.

DELIMITATIONS

Five adult male subjects were selected from the graduate physical education enrollment and from among the faculty at Kansas State University, Manhattan, Kansas. The study was conducted from February through March, 1976.

DEFINITIONS OF TERMS

Some terms used in this study required defining. The following discussion served to define those terms.

Douglas Bag

Originally, a 50 to 100 liter capacity canvas bag with a rubberized inner lining and a one-way valve attached to the neck of the bag. For this study, a rubber weather balloon served as a Douglas Bag. Throughout the manuscript, Douglas Bag was sometimes abbreviated "DB".

Tissot Tank

The Tissot Tank employed was a 120 liter capacity, water sealed, Collins Chain Compensated bell spirometer. A meter stick was provided to determine air volumes. A volume of 1.332 liters of air displaced the bell one centimeter. An air mixing fan, provided at the top of the bell, was utilized to insure proper air mixing and unbiased air sampling. The abbreviation used for Tissot Tank was "TT".

Mini Bag

The Mini Bag was made from Scotch metalized plastic, cut and molded into a six by eight inch rectangle with a stop cock inserted into

one corner. The Mini Bag's capacity was approximately 700 to 1000 cubic centimeters. Mini Bag was abbreviated "MB".

Sample Duration

Sample duration was the time interval during which air samples were being collected with each technique. Three times were designated for each technique with the exception of the Tissot Tank which had only two. The sample techniques and durations were represented by the technique abbreviation followed by the duration number in seconds, (e.g. "DB30", "TT60", "MB120" - Douglas Bag 30 seconds, Tissot Tank 60 seconds, and Mini Bag 120 seconds).

Time

In Chapter 4, time was defined as the length of time that elapsed from the start of the run until each method was obtained. Time was represented in the tables as mean times for each technique.

Chapter 2

REVIEW OF LITERATURE

Measurement has been applied to human performance since earliest times. The purpose of this paper dealt with the objective measurement of the aerobic processes. Oxygen uptake, measured in liters per minute or in milliliters per kilogram per minute (ml/kg/min.), is used as an assessment of man's ability to perform endurance activities. (1, 3, 4, 36)

Literature concerning the reliability of metabolic measurement is sparse. The following review of literature examined the relevant research concerning oxygen uptake as a measure of cardiovascular fitness and research that dealt with the methodology of obtaining oxygen uptake assessments.

OXYGEN UPTAKE AS A MEASURE

The human body's ability to utilize oxygen is dependent upon several factors such as lung capacity, stroke volume of the heart, hemoglobin levels of the blood, etc. All the physiological parameters work together to make oxygen available to the working muscle. As the physical demand on the working muscle increases, so too does oxygen consumption. Hill (15) demonstrated that there is an upper limit to the capacities of the cardiovascular and respiratory systems. This classic work demonstrated that there was a linear relationship between oxygen uptake and workload to a point where maximum oxygen uptake is reached and a plateau

occurs. Increases in workload beyond this point created greater oxygen debts and led to ultimate total fatigue and cessation of work.

Taylor, et al. (36) explored different protocol for achieving maximal oxygen consumption levels while running on a treadmill. He found that by increasing the grade, he could consistently create a plateau phase at the maximum oxygen uptake levels. This plateau was more consistent than when increases in speed alone were used. Taylor was concerned with oxygen uptake as a valid measure of cardiorespiratory performance. A coefficient of reliability of .95 was found to exist on 69 test-retest determinations. Tests remained very constant over periods up to one year in men whose physical activity did not vary widely during this time period.

Similar findings have been reported in more recent research (4, 26, 37). In a comparison of the reliabilities of maximum oxygen uptake between leg work and arm work, maximum $\dot{V}O_2$ measures of leg work involving the larger muscle groups was found to be the more reliable test. Similar recent studies (9, 12, 13, 19, 29) have been conducted to determine what activities were best suited to elicit a maximal oxygen response from the cardiorespiratory system. Faulkner, et al. (9) found running to elicit 11 percent higher maximum $\dot{V}O_2$'s than did cycling which tended to agree with Hermansen's (13) findings of a seven percent higher oxygen uptake in running than cycling. Astrand (1) compared various activities and found $\dot{V}O_2$ to be higher in running than cycling. He also found maximum $\dot{V}O_2$ measures of arm work to result in $\dot{V}O_2$'s that were 30 percent below those of cycling.

Cardiorespiratory fitness among endurance athletes, such as distance runners and cross country skiers, have reflected the highest oxygen uptake among males for treadmill running and bicycle exercise. Maximum

$\dot{V}O_2$ measures he reported were the highest at 6.17 liters/minute for highly trained males.

Oxygen uptake measures have proven valuable as measures of submaximal work performance. Studies using $\dot{V}O_2$ measures to monitor work levels on a comparison basis such as test-retest observations were numerous (18, 21, 22, 27, 29, 36). Variables such as training versus detraining, altitude versus sea level, G-stress and heat stress situations have proven to cause changes in work intensity based on oxygen consumption parameters.

Correlations between actual and predicted oxygen uptake measures have been determined to make field testing and inexpensive laboratory evaluation of oxygen uptake possible (2, 11, 16, 20, 31).

Oxygen uptake measures outside the laboratory setting appeared in the current literature. Maron (22) studied oxygen consumption of marathon runners every three miles during the 26 mile race. He observed $\dot{V}O_2$ measures that ranged from 68 to 100 percent of their maximal capacity.

Oxygen uptake evaluation allows indirect calorimetry of various activities to be examined. Valuable information concerning energy cost was computed from studies of oxygen uptake measures (7, 20); however, the details of methodology were vague.

It has been recognized that oxygen uptake is a valid measure of cardiorespiratory fitness and has many uses in the field of fitness testing. The remainder of this chapter deals with the examination of literature related to methodology of oxygen uptake measure.

METHODS OF DETERMINING OXYGEN UPTAKE

The most frequent references available were those concerned with examination of the reliability and permeability of the Douglas Bag. Literature concerning Tissot measures was either not available or written in a foreign language. The Mini Bag technique was new enough that there weren't any references available for review. Literature in the area of methods reliability, particularly with reference to the Tissot measure and the Mini Bag technique was unavailable.

The Douglas Bag Technique is the classical method for determining oxygen usage in man, and was named for its inventor, C. G. Douglas (9). Douglas' original publication described the bag set up in laboratory and field usage with a back and head harness. He suggested mixing the bag contents during measurement of volume and to draw samples of oxygen and carbon dioxide for analysis at this time.

Douglas and Priestly (10) found that even with careful selection of bags, some loss of carbon dioxide was apt to occur, and this loss was attributed to solution of CO_2 in the rubber lining of the canvas bag.

Shepard (34) made a critical examination of the Douglas Bag technique. This study examined not only loss of CO_2, but was concerned with the behavior of Douglas Bags in general. It considered other variables, particularly the volume of gas in the bag and the surface area of the bag in question. Standard Siebe Gorman (fabric coated with vulcanized rubber) with total capacities of 60-200 liters were employed. Some of the bags were new and some were up to 20 years old, but bags with structural faults were discarded. Carbon dioxide concentrations were analyzed by the standard Haldane apparatus. Oxygen concentrations were

analyzed by the standard Haldane apparatus. Oxygen concentrations were analyzed by a paramagnetic oxygen analyzer. Shepard found the amount of loss and duration of gas storage were positively correlated. He viewed the partial pressure gradient, bag surface area, and the type of gas. Shepard used a water manometer connected to the bag to determine excess pressure within the bag. There was found to be an approximate linear relationship between excess pressure and total gas content. For a given bag, he found that the rate of loss was directly related to the average partial pressure of gas within the bag. Shepard noted that this was in keeping with Graham's Law, and this suggested that in the Douglas Bag, loss of gas was occurring through pores of approximately molecular dimensions. Shepard's results showed an error of one percent in CO_2 concentrations per 15 minutes of storage. Bag age was not a factor.

Perkins (29) reported similar results. Carbon dioxide leakage was minimal. The CO_2 content of the expired air in the bag was analyzed by a Haldane apparatus after 0, 1, 2.5, 5.5, and 22 hours. With so little loss in a moderate period of time, one should feel justified in using Douglas Bags for temporary storage of expired air samples. Perkins also found no considerable increase in pressure above atmospheric with volumes up to 100 liters.

Balchum, et al. (6) investigated the permeability of Douglas Bags to carbon dioxide, oxygen, and nitrogen by measuring changes in concentrations of these gases under various conditions. Four 100 liter bags were used at room temperature (20°C) and at ambient pressure. Gas analysis was done by the Schollander-Roughton method. Balchum found a continual loss of CO_2 from the bags, and a gain of oxygen from the atmosphere, resulting in an increase in the oxygen concentration. The CO_2

to O_2 permeability ratio was found to be 6:1. These changes on O_2 concentration significantly affected R.Q. and Basal Metabolic Rates when expired air samples remained in the bags for several hours. The rate of change of concentration of a gas in a Douglas Bag depends upon the nature of the gas, the pressure gradient, and the initial volume of the gas.

Similar studies (25, 26) found negligible losses of CO_2 in bags of usual sizes. Only in extremely large bags (1,000 liters capacity) did a measureable amount of CO_2 escape over a period up to 15 minutes.

Wilmore (38) conducted research on reliability of the Mini Bag technique. He cited the biggest problem with any Mini Bag technique as being the collection of representative samples of respiratory air when employing low resistance gas meters. Wilmore found the error between actual O_2 and CO_2 concentrations and those represented in the Mini Bags to be insignificant.

Respiratory valve and system dead space is generally negated by allowing the subject to breathe through the system for a few seconds, flushing the dead space and filling it with expired air. Research on respiratory valve dead space and its effect on oxygen uptake found that even up to the largest valve dead space (Collins Triple J valve, 300 ml. dead space) oxygen uptake valves were not significantly affected (5, 18, 35).

Johnson, et al. (16) reviewed a versatile system for measuring oxygen consumption in man. His system incorporated a Tissot spirometer, a Kyfranyi-Michaelis apparatus, and a Mini Bag gas collection technique. He suggested that different collection devices should prove more efficient at different levels of exercise intensity. Johnson used the Tissot Tank

for resting measures, the Kyfranyi-Michaelis apparatus for moderate work and the Mini Bag for heavy work. His system proved reliable for measuring respiratory exchange during these three levels of exercise intensity.

Chapter 3

PROCEDURES

This study was conducted to compare three methods of metabolic measurement. The exercise physiology research laboratory at Kansas State University served as the testing environment during the spring semester of the academic year of 1976. The procedures used in this study are described and summarized in the following portions of this chapter.

SUBJECTS

Five adult males volunteered to participate as subjects in this study. The age and height and weight of each subject was recorded and appears in Table 1.

Table 1

Subject, Age, Height and Weight

Subject	Age	Height in cm.	Mass in kg.
1	24	190.5	82
2	26	167.6	70
3	25	182.8	84
4	24	178	79
5	34	190.5	84
Mean	26.6	181.9	29.8

All subjects were determined to be eligible based on their levels of fitness. All subjects were recreational joggers for personal fitness averaging from 25 to 30 miles per week.

Informed Consent

Statements explaining the conditions of data collection, along with liability release and a form concerning cessation of participation were given to all subjects. These forms were acknowledged by the subjects' signatures. A sample of the form appears in Appendix A.

Treadmill Speed and Running Experience

Of the five subjects involved in this study, three were quite familiar with treadmill running. All subjects were given trial runs on the treadmill. These trial runs accomplished three objectives. First, it provided practice and running experience for each subject involved. Second, it afforded the attending technicians time to acquaint themselves with the techniques used for metabolic measurement. Third, it allowed treadmill speeds to be determined based on a steady-state exercise intensity of approximately 70 percent of the maximum oxygen consumption of each subject.

TESTING PROCEDURE

The following discussion will involve testing time, equipment and preparation, and data collection.

Testing Time

Testing time was determined by the availability of subjects and laboratory assistants. This time was most often between the hours of 11:00 a.m. and 1:30 p.m. Because of schedule conflicts, no more than

three people were tested on a single day. Total data collection took approximately two months.

Equipment and Preparation

On days which data was collected, the room temperature of the exercise physiology laboratory was recorded from web bulb and dry bulb thermometers. Barometric pressure was recorded, following determination from a mercury barometer. These recordings made it possible to determine the partial pressure of water in the air (7) as well as the standard temperature pressure dry (STPD) correction factor of the inspired air of the subject.

One hour prior to testing, the oxygen and carbon dioxide analyzers were simultaneously turned on to insure adequate warm up time for the instruments. A Beckman LB-1 carbon dioxide analyzer was calibrated daily with a gas of known quantity of carbon dioxide (5 percent). The calibration for room air carbon dioxide was 0.03 percent. The Beckman E-2 oxygen analyzer was calibrated prior to testing with Helium gas for a zero percent reading and a room air oxygen tension of 20.93 percent. These calibrations were rechecked after the measurement of every three samples through the testing. The analysis remained stable, and required no recalibration after the initial daily adjustment.

Volumes of inspired air were measured by a Parkinson-Cowan Ventilometer. The ventilometer was calibrated for the study by use of the Collins chain compensated 120 liter bell spirometer (Tissot Tank) which also served as a gas collection device. Six Mini Bags were also used as a means of gas collection. These metalized collection bags were constructed from a film consisting of a sheet of aluminum sandwiched between two layers of polyethylene film. The material was manufactured by 3M

Company, Film and Allied Products Division, and was identified as Scotchpak film. Supplemental apparatus for gas collection included rubber hosing, an expanded plastic air mixing chamber, a Collins Triple J valve, rubber mouthpieces, a Neptune Pressure dyna pump, and Y valve positioned at the end of the open circuit system to control air flow to the proper collection device. Figure 1 gives a graphic display of the testing environment.

The Quinton Model 640 treadmill provided the facility on which the subjects ran. Treadmill speeds were determined for each subject and checked via the treadmill revolution counter and elapsed time at the programmed speed.

The subjects' inspired air was recorded from the Parkinson-Cowan Ventilometer as previously mentioned. A Collins Triple J valve was used in conjunction with a rubber mouthpiece and nose clip to obtain expired air samples from the subjects. The mouthpiece and valve were sterilized prior to each test and suspended above the treadmill at a height convenient for each subject.

Prior to the start of data collection, all air sample bags were checked for leakage by suspending them in a tank of water with air samples inside. Before data collection on each specific day of testing, the Mini Bags were evacuated using a vacuum pump and the Douglas Bags were evacuated by wrapping them tightly around the hand and inserting the stopper. This was done to prevent contamination of air samples. The Tissot Tank was flushed and sealed prior to collection of each sample of gas.

Data Collection

Subjects complied with the request to wear jogging shorts, socks, and jogging shoes while participating in the data collection.

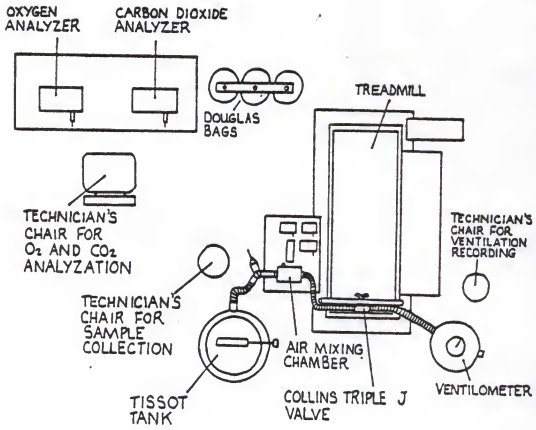

Figure 1

Testing Environment

Prior to the 15 to 20 minute exercise session involving actual data collection, the order of samples was recorded on a chalk board visible to all. It remained on the board until all samples were obtained. This order of samples was generated from a table of random numbers, and it appears in Appendix B. Every testing session, a new order for the eight samples was prepared in this random fashion.

Four technicians were given their assignments and data recording sheets prior to each run. The subject was instructed to position the nose clip and stand on the sideboard adjacent to the treadmill. Treadmill speed was checked prior to the start of the exercise bout. The subject was then instructed to start running. Subjects were allowed a three minute warm-up interval to reach steady-state prior to the first sample collection.

Actual gas collection was done continuously for the designated duration (i.e., 30, 60, or 120 seconds) for both the Tissot Tank and the Douglas Bags. Gas collection for the Mini Bags was interspersed equally over the predetermined time interval.

Volumes of ambient air ($\dot{V}$ air) were determined simultaneously for the Mini Bags and Tissot Tank samples. Douglas Bag samples were flushed back through the gas meter after gas analyzation had been determined.

Gas collection for the Tissot Tank and Douglas Bags was conducted through the Y valve at the distal end of the expanded air mixing chamber. Mini Bag samples were extracted directly from a medial port in the mixing chamber using the dyna pump. Figure 2 demonstrates the arrangement.

Oxygen and carbon dioxide concentrations from the gas samples were determined immediately following collection by the technicians. A hierarchy was established with the Douglas Bags being emptied first

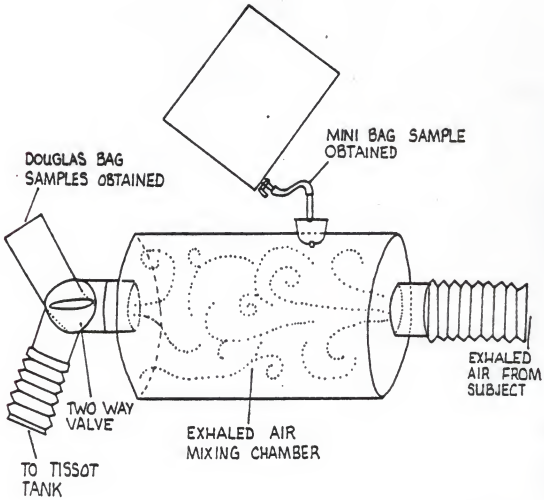

Figure 2

Air Mixing Chamber

because of their porous nature. The others followed in random order. Total time involved in gas collection and analysis was approximately 25 minutes. Subjects were allowed three minutes of warm up until steady-state was assumed to be achieved. Gas collection followed immediately.

SUMMARY

Subjects were tested during the noon hours over a period of two months. Tissot Tank, Douglas Bag, and Mini Bag techniques were used in a random order to obtain expired air samples. Subjects warmed up for the first three minutes of a 20 minute treadmill run and expired air samples were collected immediately after the warm up period. Technicians determined oxygen and carbon dioxide levels immediately after collection. This entire testing sequence took about 35 minutes.

STATISTICAL TREATMENT OF THE DATA

Data were statistically analyzed using the two-way analysis of variance (Two-Way ANOVA) designed for repeated measures. When a significant F was obtained, a Least Significant Difference (LSD) was used to locate where these differences occurred. Significant F's were determined at the .05 level of significance.

The computing center at Kansas State University provided the facilities to perform all calculations.

Chapter 4

RESULTS AND DISCUSSION

The purpose of this study was to compare the parameters of $\dot{V}O_2$, ventilation, O_2 percent, CO_2 percent and R.Q. among three different techniques and three different durations of gas collection during steady-state treadmill running.

The statistical treatments employed were the two-way ANOVA and, when significant differences were found, the Fisher techniques of Least Significant Differences (Fisher's LSD). The results obtained were presented and discussed in this chapter.

$\dot{V}O_2$ MEASURED IN LITERS PER MINUTE

Mean $\dot{V}O_2$, measured in liters per minute, for subject method and trial, appear in Table 2. Mean $\dot{V}O_2$ for method by trial were recorded and appear in Appendix C.

Table 2

Mean $\dot{V}O_2$ in Liters Per Minute for Subject, Method and Trial

Subject	$\dot{V}O_2$	Method	$\dot{V}O_2$	Trial	$\dot{V}O_2$
1	3.37	MB30	3.43	1	3.34
2	2.98	MB60	3.39	2	3.41
3	3.54	MB120	3.44	3	3.29
4	3.29	DB30	3.31	4	3.22
5	3.26	DB60	3.45	5	3.25
		DB120	3.13	6	3.11
		TT30	3.01	7	3.35
		TT60	3.12	8	3.33

The results of the two-way ANOVA appeared in Table 3 and indicated significant differences did exist in method, trial and subjects.

Table 3

Summary of Two-Way ANOVA for $\dot{V}O_2$ in Liters per Minute

Source	df	SS	MS	f
Subject	4	8.62	2.16	28.81*
Method	7	4.34	.62	8.28*
Error 1	28	2.09	.07	
Trial	7	1.78	.25	4.40*
Method x Trial	49	1.96	.04	.69
Error 2	160	9.23	.06	

* Significant at the .05 level

The Fisher's LSD summary of method and trial means in Table 4 indicated significant differences existed among three groups of methods. $\dot{V}O_2$'s measured by TT30, TT60, and DB120 were significantly lower than DB30 and MB60 which were also significantly less than DB60, MB30, MB120. There were, however, no significant differences within these three groups.

Significant differences were found to exist among four trial groups. Measures for trial 1 and trial 2 were found to be significantly less than those made by trials 6, 7, 8. Similarly, $\dot{V}O_2$ measures made by trials 1, 2, 3 and 4 were all significantly less than 8. Trials within these groupings showed no significant differences.

Table 4

$\dot{V}O_2$ in Liters per Minute Means and Nonsignificant Groupings Determined by Fisher's LSD*

Method	$\dot{V}O_2$	Trial	$\dot{V}O_2$
TT 30	3.05	1	3.11
TT 60	3.13	2	3.22
DB 120	3.16	3	3.29
DB 30	3.33	4	3.25
MB 60	3.38	5	3.33
DB 60	3.39	6	3.34
MB 30	3.42	7	3.35
MB 120	3.43	8	3.41

* Bars denote nonsignificant grouping

$\dot{V}O_2$ MEASURED IN MILLILITERS PER KILOGRAM PER MINUTE

Mean $\dot{V}O_2$ measured in ml/kg/min. for subject, method and trial were presented in Table 5. Means for method by trial were presented in Appendix D.

Table 5

Mean $\dot{V}O_2$'s Measured in Milliliters per Kilogram per Minute for Subject, Method and Trial

Subject	$\dot{V}O_2$	Method	$\dot{V}O_2$	Trial	$\dot{V}O_2$
1	42.6	MB 30	43.3	1	42.0
2	42.0	MB 60	42.8	2	43.0
3	42.0	MB 120	43.4	3	41.5
4	42.8	DB 30	41.7	4	40.5
5	38.1	DB 60	43.7	5	40.9
		DB 120	39.4	6	39.4
		TT 30	38.6	7	42.3
		TT 60	39.2	8	42.2

The results of the two-way ANOVA for $\dot{V}O_2$ measured in ml/kg/min. were tabled and appear in the text in Table 6.

Table 6

Summary of the Two-Way ANOVA for $\dot{V}O_2$ in ml/kg/min.

Source	df	SS	MS	F
Subject	4	681.42	170.36	13.25*
Method	7	743.57	106.22	8.26*
Error 1	28	359.88	12.86	
Trial	7	277.43	39.63	4.19*
Method x Trial	49	328.89	6.71	.71
Error 2	160	1514.03	9.46	

* Significant at the .05 level

These results demonstrated that mean $\dot{V}O_2$ in ml/kg/min. differed significantly among subject, method and trial.

Table 7 contains the Fisher's LSD for $\dot{V}O_2$ in ml/kg/min. for trial and method.

Table 7

$\dot{V}O_2$ in ml/kg/min. Treatment Means and Nonsignificant Groupings Determined by Fisher's LSD*

Method	$\dot{V}O_2$	Trial	$\dot{V}O_2$
TT 30	32.42	1	39.34
TT 60	39.42	2	40.49
DB 120	39.72	3	40.98
DB 30	42.00	4	41.49
MB 60	42.21	5	42.05
DB 60	42.70	6	42.17
MB 30	42.97	7	42.30
MB 120	43.35	8	42.99

* Bars denote non-significant groupings

Results of these treatments indicated that two statistical groups of methods were significantly different. It was found that TT 30, TT 60, and DB 120 were significantly smaller than all other measured in ml/kg/min. Further examination of the results of the treatments of trial means found trial 1 was significantly smaller than trials 5, 6, 7, and 8. The following differences among statistical groups was observed. Trials 1 and 2 were significantly lower than trials 5, 6, 7, and 8. Trials 1, 2, 3, and 4 were significantly less than trial 8.

VENTILATION

Mean ventilation measured in liters per minute for subject, method and for trial appeared in Table 8.

Table 8

Mean Ventilation in Liters per Minute for Subject, Method and Trial

Subject	$\dot{V}e$	Method	$\dot{V}e$	Trial	$\dot{V}e$
1	89.9	MB 30	83.2	1	81.3
2	70.0	MB 60	81.9	2	81.4
3	84.5	MB 120	80.8	3	79.4
4	79.8	DB 30	78.1	4	79.7
5	77.3	DB 60	79.1	5	80.5
		DB 120	79.6	6	78.6
		TT 30	79.6	7	79.7
		TT 60	79.9	8	81.2

Appendix E provided the data concerning mean ventilation for method by trial. In Table 9, the results of the two-way ANOVA were recorded. Among these results, significant differences were determined for subject and method.

Table 9

Summary of Two-Way ANOVA for Ventilation
in Liters per Minute

Source	df	SS	MS	F
Subject	4	13721.22	3430.30	179.18*
Method	7	469.92	65.99	3.45*
Error 1	28	536.04	19.14	
Trial	7	219.43	31.35	1.27
Method & Trial	49	618.03	12.61	.51
Error 2	160	3944.83	24.66	

* Significant at the .05 level

To determine where differences for method existed, the Fisher's LSD to examine non-significant differences was employed. Analysis of the methods means presented in Table 10 yielded that results for methods DB 30 and DB 60 were significantly lower than those of methods MB 30 and MB 60. Methods MB 120, DB 120, TT 30 and TT 60 were found to be significantly lower than method MB 30.

Table 10

Ventilation Treatment Means in Liters per Minute and
Non-Significant Groupings Determined by Fisher's LSD*

Method	Ventilation	
DB 30	78.62	|
DB 60	78.66	|
DB 120	79.54	| |
TT 30	79.57	| |
TT 60	80.18	| |
MB 120	80.45	| |
MB 60	81.52	|
MB 30	83.26	|

* Bars denote non-significant groupings

OXYGEN PERCENT

Mean oxygen percent for subjects, methods and trials was tabled and presented below. Means for method by trial were presented in Appendix F.

Table 11

Mean Oxygen Percent for Subject, Method and Trials

Subject	O_2%	Method	O_2%	Trial	O_2%
1	17.2	MB 30	16.8	1	16.8
2	16.7	MB 60	16.8	2	16.8
3	16.7	MB 120	16.7	3	16.8
4	16.8	DB 30	16.7	4	16.9
5	16.7	DB 60	16.6	5	16.9
		DB 120	17.0	6	16.9
		TT 30	17.0	7	16.7
		TT 60	17.0	8	16.8

The analysis of variance for oxygen percent was recorded in Table 12. A significant difference was found to exist among methods.

Table 12

Summary of Two-Way ANOVA for Oxygen Percent

Source	df	SS	MS	F
Subject	4	9.63	2.41	38.87*
Method	7	4.83	.69	11.13*
Error 1	28	1.73	.06	
Trial	7	.81	.12	1.75
Method x Trial	49	1.67	.03	.52
Error	160	10.54	.07	

* Significant at the .05 level

Table 13

Oxygen Percent Treatment Means and Non-Significant Groupings Determined by Fisher's LSD*

Method	Oxygen Percent
MB 60	16.61
MB 120	16.68
DB 30	16.71
MB 60	16.79
MB 30	16.83
DB 120	16.94
TT 60	17.00
TT 30	17.06

* Bars denote non-significant groupings

By observation of Table 13, it became apparent that there were many differences. By examination of those methods that were statistically similar, six groups were delineated. Progressing through the six groups from lowest oxygen percentage to highest, reflected the following similar groupings: (MB 60, MB 120, DB 30), (MB 120, DB 30, MB 60), (MB 60, MB 30), (MB 30, DB 120), (DB 120, TT 60), (TT 60, TT 30). By observation, it became apparent that the last method in each group was also similar to the first method of the following group.

CARBON DIOXIDE PERCENT

Mean carbon dioxide percent of expired air for subjects, methods and trials was tabled and is presented in Table 14. Mean carbon dioxide percent for method by trial appeared in Appendix G.

Table 14

Mean Carbon Dioxide Percent for Subject, Method and Trial

Subject	CO_2%	Method	CO_2%	Trial	CO_2%
1	3.68	MB 30	3.91	1	3.92
2	3.98	MB 60	3.92	2	3.79
3	4.26	MB 120	4.08	3	3.93
4	4.01	DB 30	4.00	4	4.01
5	3.93	DB 60	4.12	5	3.83
		DB 120	3.92	6	4.01
		TT 30	3.91	7	3.95
		TT 60	3.92	8	4.10

A significant difference for both method and trial were determined by the two-way ANOVA presented in Table 15.

Table 15

Summary of Two-Way ANOVA for Carbon Dioxide Percent

Source	df	SS	MS	F
Subject	4	8.15	2.04	103.78*
Method	7	.88	.13	6.40*
Error 1	28	.55	.02	
Trial	7	1.85	.26	4.13*
Method x Trial	49	1.00	.02	.32
Error 2	160	10.24	.06	

* Significant at the .05 level

Further statistical treatment of the means using Fisher's LSD determined non-significant groupings and was presented in Table 16.

Table 16

Carbon Dioxide Percent Treatment Means and
Non-Significant Groupings Determined by Fisher's LSD*

Method	CO_2%	Trial	CO_2%
TT 30	3.89	1	3.79
MB 30	3.89	2	3.83
TT 60	3.90	3	3.92
DB 120	3.90	4	3.93
MB 60	3.91	5	3.95
DB 30	3.97	6	4.01
MB 120	4.01	7	4.01
DB 60	4.07	8	4.10

* Bars denote non-significant groupings

Examination of the methods means revealed that TT 30, TT 60, MB 30, MB 60, DB 120 were significantly less than MB 120 and DB 60. Douglass Bag 30 was significantly different from all other methods except MB 60 and MB 120. Method MB 120 was different from all other methods except DB 60 and DB 30. Method DB 60 was significantly larger than all other methods except MB 120.

Observation of the trial means revealed that trial 1 differed significantly from trials 3, 4, 5, 6, 7, and 8. Trial 8 was significantly different from trials 1, 2, 3, and 4. Trial 2 was significantly different from trials 6, 7, and 8.

RESPIRATORY QUOTIENT (R.Q.)

Mean R.Q. data for subjects, methods and trials was recorded in Table 17. Mean R.Q. data for methods by trials was entered in Appendix H.

Table 17

Mean Respiratory Quotient for Subjects, Methods and Trials

Subject	R.Q.	Method	R.Q.	Trial	R.Q.
1	.98	MB 30	.95	1	.95
2	.94	MB 60	.95	2	.92
3	1.01	MB 120	.96	3	.95
4	.97	DB 30	.95	4	.99
5	.93	DB 60	.95	5	.95
		DB 120	.99	6	1.01
		TT 30	1.01	7	.94
		TT 60	1.00	8	1.00

By examination of the two-way ANOVA presented in Table 18, significant differences were found to exist in methods and trials.

Table 18

Summary of Two-Way ANOVA for Respiratory Quotient

Source	df	SS	MS	F
Subject	4	.16	.04	25.34*
Method	7	.13	.02	11.58*
Error 1	28	.04	.00	
Trial	7	.19	.03	4.51*
Method x Trial	49	.05	.00	.15
Error 2	160	.96	.01	

* Significant at the .05 level

Analysis of the results of Fisher's LSD for methods in Table 19 determined that R.Q. measurements for methods MB 30, MB 60, MB 120, DB 30, and DB 60 were significantly lower than methods DB 120, TT 30, and TT 60. From Table 19, results showed trial 1 differed significantly from trials 3, 4, 5, 6, 7, and 8. Trials 1 and 2 differed significantly from

trials 6, 7, and 8. Trials 1, 2, 3, 4, and 5 differed significantly from trials 6, 7, and 8.

Table 19

R.Q. Treatment Means and Non-Significant Groupings for Method and Trial Determined by Fisher's LSD*

Method	R.Q.	Trial	R.Q.
DB 30	.94	1	.92
MB 120	.94	2	.94
DB 60	.94	3	.95
MB 60	.95	4	.95
MB 30	.95	5	.95
DB 120	.98	6	.99
TT 60	.99	7	1.00
TT 30	1.00	8	1.00

* Bars denote non-significant groupings

TIME

Means for time measured in minutes from the start of each run for sampling of methods for subjects, methods, and trials was presented in Table 20. Means for method by trial were reported in Appendix I.

Table 20

Means for Time for Subject, Method and Trial

Subject	Time	Method	Time	Trial	Time
1	9.9	MB 30	9.3	1	10.1
2	9.1	MB 60	9.4	2	9.8
3	9.3	MB 120	8.7	3	9.9
4	9.9	DB 30	11.5	4	9.7
5	10.8	DB 60	7.8	5	9.4
		DB 120	10.3	6	9.1
		TT 30	10.7	7	11.8
		TT 60	10.7	8	9.5

Results of the two-way ANOVA for time were presented in Table 21. A significant difference was found to exist in method. Fisher's LSD was used to determine non-significant grouping among the methods time. Table 22 was constructed to present the Fisher's LSD for time.

Table 21

Summary of Two-Way ANOVA for Time into the Exercise Bout

Source	df	SS	MS	F
Subject	4	855.6 78	213.9	2.19
Method	7	2313.8 75	330.5	3.39*
Error 1	28	2731.0 75	197.5	
Trial	7	856.1 57	122.3	.77
Method x Trial	49	8070.9 59	164.7	1.04
Error 2	160	28355.1 31	158.4	

* Significant at the .05 level

Table 22

Time Treatment Means and Non-Significant Groupings Determined by Fisher's LSD*

Method	Time
DB 60	8.13
MB 120	9.22
MB 60	9.28
MB .30	9.43
DB 120	10.00
TT 60	10.96
TT 30	11.10
DB 30	11.20

* Bars denote non-significant groupings

DISCUSSION

The primary purpose of this study was to compare three techniques of gas collection using varying durations of collection. The methodologies employed were the Douglas Bag, Tissot Tank and Mini Bag. The durations were one-half minute, one minute and two minutes.

The statistical treatment of the two-way ANOVA was applied to all parameters and when differences were found, the Fisher's LSD treated the means to locate the differences. The Fisher's LSD was applied to the subject, method, trial and method by trial. Significant differences were often found among subjects. Because of subject variability, discussion of the differences among trials, which was a repeated measure of each technique over all subjects, was unnecessary. Personal individual differences accounted for these statistical differences.

The parameters of ventilation, oxygen percent, carbon dioxide percent, and respiratory quotient demonstrated significant differences most often among the techniques and durations. The relative interplay all these variables have in calculating oxygen uptake, however, can explain these significant differences. It, therefore, became unnecessary to discuss those variabilities at this juncture. In the final analysis, oxygen uptake was the parameter of primary importance here as it has been in previous investigations (1, 4, 9, 12, 13, 19, 29). Observation of oxygen uptake determinations in liters per minute and milliliters per kilogram per minute were done in this study to compare the measurement techniques of the Douglas Bag, Tissot Tank, and Mini Bag.

Table 7 demonstrated that oxygen uptake in ml/kg/min. for methods exhibited two statistically different groups. The Tissot Tank method and

the Douglas Bag with the longest duration were significantly lower in their measurements of oxygen uptake. Johnson (16) alluded to the method of Tissot measure for gas collection as being more suitable for physical measurement during a resting state. Because this was a steady state measurement at approximately 70% of the max $\dot{V}O_2$, these differences in Tissot measure would tend to support this concept. The literature in this area was sparse. Johnson's (16) article was the only one that had examined this phenomenon. However, an examination of Table 4 showed a definite and regular increase in oxygen consumption among trial measurements from trial 1 to trial 8.

Table 4 demonstrated oxygen uptake measures for method and trial. It is apparent that oxygen uptake increased regularly from trial 1 through trial 8. This difference was statistically significant as evidenced by the F ratio for trials in Table 3. This suggested that the oxygen uptake increased for each subject as he exercised.

Expanding on this view, observation of Table 16 found carbon dioxide percent increasing from trial 1 through trial 8. This increase was statistically significant. Careful scrutiny of Table 15 beared this out. The F ratio for trials was significant.

Similarly, Table 19 demonstrated that respiratory quotient increased from trial 1 through trial 8. Table 18 demonstrated that the F ratio for trials was also significant.

Oxygen uptake was found to significantly increase for all subjects during their exercise bout from trial 1 through trial 8. If one retains the assumption that the subjects were exercising at steady state throughout the exercise bout, then it would appear that the measures obtained were not a dependable representation of the metabolism that was

taking place. A more tenable approach to this dilemma might be to reject the assumption that the subjects were exercising at steady state. It has been established that carbon dioxide demonstrated a statistically significant increase as did respiratory quotient during the exercise bout. By reason of explanation it could be speculated that the subjects did in fact fatigue causing the carbon dioxide and respiratory quotient shift mentioned. As the subjects fatigued the respiratory quotient increased. An increase in oxygen uptake was reflected as the subjects' metabolic state called for more energy from the carbohydrate reserves.

There seemed to be more evidence to suggest that the subjects did not exercise through their full 20 minute bout at steady state. If this was the case then the results obtained to determine the constancy of the measurement techniques employed must be viewed with some apprehension.

Table 22 demonstrated the mean time elapsed from the start of the run at which each technique was taken. There appeared to be a time relationship between Tissot measures. There was no statistical difference between TT 30 and TT 60 as to when each technique was collected. This suggests that they were both used very closely together during the exercise bout. If this could be held accountable for the differences, then a re-examination of the random order of collection would be in order. There was no difference in $\dot{V}O_2$ measured by either Tissot and there was no difference in the time when the measures were taken.

Numerous occurrances in the literature (3, 4, 6, 9, 10, 15, 16, 26, 29) demonstrated the consistency of these types of measurements of oxygen uptake. In an attempt to explain the differences that occurred in $\dot{V}O_2$ measures with the different techniques used in this study, this author found few useful resolutions. Subject variability might have

played a role. Spurious reading by the technicians could have accounted for further errors. A more logical approach from which to view the problem is discussed further in the recommendations for further research in the following chapter.

Data from this study indicated a difference among methods with respect to $\dot{V}O_2$. Differences in these data were attributed to the fact that measurements of oxygen uptake were taken over five subjects rather than a repeated measures technique over one subject. There were no attempts made to determine the permeability of the type of Douglas Bags and Mini Bags used in this study. Measurement in this study involved only one level of working capacity, which was approximately 70% of each individual's maximum oxygen uptake.

All methods employed have demonstrated their dependability and are acceptable techniques. When oxygen uptake measures are used as an absolute measure, such as for determination of max $\dot{V}O_2$ or resting $\dot{V}O_2$, one should choose the technique carefully as Johnson (16) suggested.

As a relative measure to indicate change due to independent variables such as training or altitude, the type of technique would not be as critical. It would then be a repeated measures and would require only that the same technique be used throughout. All three techniques employed in this study are used routinely in laboratory work.

Chapter 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

In this study, five well-trained adult males served as subjects, each running on the treadmill for approximately 20 minutes. Subjects exercised at approximately 70 percent of their total aerobic capacity as measured by oxygen uptake. The purpose of this study was to compare oxygen uptake, ventilation, oxygen percent, carbon dioxide percent and respiratory quotient among three gas collection techniques and among three collection time durations.

The results indicated significant differences existed among the methods used here. Differences were numerous among oxygen concentrations, carbon dioxide concentrations, R.Q., ventilations, and trials. These particular differences can be accounted for by the fact that they vary as a function of their relative interplay in determining oxygen uptake.

Oxygen uptake measured in liters per minute and milliliters per kilogram per minute were the primary evaluation mode of the measurements taken. The results of oxygen uptake determinations revealed significant differences existed in liter per minute as well as milliliters per kilogram per minute calculations. Measures for TT 30, TT 60 and DB 120 differed significantly from the other measures employed, as these measures were found to be lower. They were also different in the time they were taken.

CONCLUSIONS

The following conclusions were drawn from the data provided by this study and considered only within the limits of this study.

1. These data indicated there can be a statistically significant difference among methodologies for determining oxygen uptake.

2. The methodology involving the Tissot Tank measures resulted in significant differences in $\dot{V}O_2$. These measures were significantly lower than all other techniques (except DB 120). It was also found that the Tissot Tank measures were obtained significantly later in the exercise bout than other measures. From these results, it was concluded that there existed some sort of interaction between the method and time, or possibly $\dot{V}O_2$ and time into the exercise bout. With consideration of Johnson's (16) research, this suggested that the Tissot Tank measured during a non-resting state exercise level with the time interaction leaves these results inconclusive.

3. Based on the data obtained it was questionable that all subjects exercised at steady state throughout the data collection. The purpose of the study was to examine the techniques for their consistency of measurement. If the assumption of steady state exercise is rejected, then the results obtained remain inconclusive.

RECOMMENDATIONS

The results and conclusions of this study provide the following recommendations for those interested in methodology of oxygen uptake measurement and research in this area.

Recommendations for Methodology Procedures

1. Based on this study, where intercomparison data from pretest to post-test oxygen uptake measures are used to determine the effects of an independent variable; it is recommended that the same methodology be employed from pretest to post-test to avoid any spurious methodological change in measurement.

Recommendations for Further Research

1. It is recommended that in the future, an attempt be made to sample air using all techniques simultaneously.

2. It is recommended that the consistency of each technique be checked without a possible bias of individual differences among subjects. This could be accomplished by using one subject and doing repeated measures to obtain the desired data.

3. It was established that there was a significant difference in when each technique was used during the exercise bout. This suggested that the order was not random. It is recommended that in the future a Latin Squares design be employed to insure random variation in measurement order.

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APPENDIX A

Subject Participation Consent Form

Exercise Physiology Research
Department of Health, Physical
Education, and Recreation
Kansas State University
Manhattan, Kansas

Date_____

I _____ have voluntarily consented to have the Personnel of the Department of Health, Physical Education and Recreation study my performance on treadmill running in conjunction with research. I understand that I will run for 15 minutes at a constant rate of speed and an unchanging elevation on the treadmill for three different days. I understand that the run will take place no sooner than 3 hours after a meal and that my weight and heart rate will be taken before and after the run and that my VO_2, R.Q. and ventilation will be monitored throughout the run. I am aware of the fact that I will be required to breathe into a mouthpiece while wearing a nose clip throughout the run.

I waive any possibility of personal damage which may accrue to such a study in the future and accept the responsibility for consenting to participate in this study. To my knowledge, I am not infected with a contagious disease, or limited by a physical condition that would preclude the treadmill running.

Should any additional information concerning the study be requested by me, I am aware that the information will be readily available from the personnel conducting the study. I understand that at any time, I may stop the treadmill and/or withdraw from the study.

_____ Date _____
Subject's Signature

APPENDIX B

Random Assignments

I	II	III	IV	V	VI	VII	VIII
DB 30	DB 30	MB 30	DB 120	MB 30	DB 120	MB 120	MB 120
TT 60	MB 120	TT 60	DB 60	MB 120	TT 30	MB 30	TT 30
TT 30	TT 30	DB 60	TT 30	DB 60	MB 120	DB 30	MB 60
DB 60	MB 30	MB 120	TT 60	MB 60	TT 60	MB 60	TT 60
MB 30	MB 60	MB 60	MB 120	TT 30	MB 60	TT 60	DB 30
MB 120	TT 60	TT 30	MB 30	DB 120	DB 30	DB 60	DB 60
DB 120	DB 60	DB 120	DB 30	TT 60	DB 60	DB 120	MB 30
MB 60	DB 120	DB 30	MB 60	DB 30	MB 30	TT 30	DB 120

IX	X	XI	XII	XIII	XIV	XV
DB 60	DB 120	MB 30	DB 30	MB 120	DB 60	TT 60
TT 60	MB 30	DB 120	TT 30	TT 60	MB 60	DB 120
TT 30	MB 120	MB 120	DB 60	TT 30	MB 120	DB 30
MB 30	MB 60	DB 60	TT 60	MB 60	TT 30	MB 30
DB 120	DB 30	TT 60	MB 30	MB 30	DB 120	MB 60
MB 120	DB 60	TT 30	MB 60	DB 30	MB 30	TT 30
DB 30	TT 30	DB 30	MB 120	DB 60	DB 30	MB 120
MB 60	TT 60	MB 60	DB 120	DB 120	TT 60	DB 60

APPENDIX C

Means and Standard Error
For VO_2 in Liters Per Minute For
Method By Trial

Method	Trial	Mean	Standard Error
1	1	3.4429932	0.109770
1	2	3.4685946	0.109770
1	3	3.345946	0.109770
1	4	3.3575935	0.109770
1	5	3.4197931	0.109770
1	6	3.2435417	0.142419
1	7	3.5552006	0.174739
1	8	3.5421810	0.174739
2	1	3.4603920	0.109770
2	2	3.4605932	0.109770
2	3	3.3231945	0.109770
2	4	3.2779932	0.109770
2	5	3.3633928	0.109770
2	6	3.3558741	0.142419
2	7	3.3941994	0.174739
2	8	3.4161825	0.174739
3	1	3.4097929	0.109770
3	2	3.5919924	0.109770
3	3	3.5381927	0.109770
3	4	3.4985924	0.109770
3	5	3.3315945	0.109770
3	6	3.1498756	0.142419

APPENDIX C

Continued

Method	Trial	Mean	Standard Error
3	7	3.5516987	0.174739
3	8	3.3886824	0.174739
4	1	3.3315935	0.109770
4	2	3.3645945	0.109770
4	3	3.4345942	0.109770
4	4	3.1813955	0.109770
4	5	3.4097948	0.109770
4	6	3.0502100	0.142419
4	7	3.4456997	0.174739
4	8	3.4071836	0.174739
5	1	3.3781929	0.109770
5	2	3.5787926	0.109770
5	3	3.599935	0.109770
5	4	3.2591944	0.109770
5	5	3.1839952	0.109770
5	6	3.1982088	0.142419
5	7	3.3186998	0.174739
5	8	3.7211809	0.174739
6	1	3.3009939	0.109770
6	2	3.2981958	0.109770
6	3	3.1635962	0.109770
6	4	3.1163960	0.109770
6	5	3.1547966	0.109770
6	6	2.9928780	0.142419

APPENDIX C

Continued

Method	Trial	Mean	Standard Error
6	7	3.1572027	0.174739
6	8	3.0756865	0.174739
7	1	3.0441933	0.109770
7	2	3.2141943	0.109770
7	3	2.9397964	0.109770
7	4	2.9917955	0.109770
7	5	3.1051960	0.109770
7	6	3.0058775	0.142419
7	7	3.0027027	0.174739
7	8	3.1266899	0.174739
8	1	3.3383832	0.109770
8	2	3.3119926	0.109770
8	3	3.0473948	0.109770
8	4	3.0839949	0.109770
8	5	3.0321951	0.109770
8	6	2.8738747	0.142419
8	7	3.3986999	0.174739
8	8	2.9641676	0.174739

APPENDIX D

Means and Standard Errors For VO_2
In Milliliters Per Kilogram Per Minute
For Method By Trial

Method	Trial	Mean	Standard Error
1	1	43.3698883	1.411922
1	2	43.7118988	1.411922
1	3	42.1998901	1.411922
1	4	42.2738953	1.411922
1	5	43.1278992	1.411922
1	6	41.0900421	1.831875
1	7	44.8602142	2.247686
1	8	45.0348816	2.247586
2	1	43.7678680	1.411922
2	2	43.6218872	1.411922
2	3	41.8918915	1.411922
2	4	41.2059021	1.411922
2	5	42.3739166	1.411922
2	6	42.4500275	1.831875
2	7	42.9102173	2.247586
2	8	43.4099121	2.247586
3	1	42.9058990	1.411922
3	2	45.4138947	1.411922
3	3	44.5358887	1.411922
3	4	44.1259003	1.411922
3	5	42.0319366	1.411922
3	6	39.9333954	1.831875
3	7	44.9502106	2.247586

APPENDIX D

Continued

Method	Trial	Mean	Standard Error
3	8	42.9199371	2.247586
4	1	41.9779053	1.411922
4	2	42.3179321	1.411922
4	3	43.1979065	1.411922
4	4	40.0159302	1.411922
4	5	43.0279388	1.411922
4	6	38.6167450	1.831875
4	7	43.5602417	2.247586
4	8	43.2699280	2.247586
5	1	42.3838806	1.411922
5	2	45.1418915	1.411922
5	3	44.8198853	1.411922
5	4	40.9419098	1.411922
5	5	40.1939240	1.411922
5	6	40.5933685	1.831875
5	7	42.0301971	2.247586
5	8	47.6798859	2.247586
6	1	41.5499115	1.411922
6	2	41.4939423	1.411922
6	3	39.8279419	1.411922
6	4	39.0839539	1.411922
6	5	39.8139638	1.411922
6	6	37.8434296	1.831875
6	7	39.7052612	2.247586

APPENDIX D

Continued

Method	Trial	Mean	Standard Error
6	8	38.6249847	2.247586
7	1	38.3739166	1.411922
7	2	40.5659332	1.411922
7	3	37.0559540	1.411922
7	4	37.5939484	1.411922
7	5	39.0319672	1.411922
7	6	37.9801025	1.831875
7	7	37.6102753	2.247586
7	8	39.1750183	2.247586
8	1	42.1058350	1.411922
8	2	41.6558838	1.411922
8	3	38.3679047	1.411922
8	4	38.7058716	1.411922
8	5	38.2779083	1.411922
8	6	36.1933746	1.831875
8	7	42.8001862	2.247586
8	8	37.2195892	2.247586

APPENDIX E

Means and Standard Errors
For Ventilation in Liters Per Minute
For Method By Trial

Method	Trial	Mean	Standard Error
1	1	84.9438782	2.183319
1	2	84.5178833	2.183319
1	3	80.4659119	2.183319
1	4	81.3299255	2.183319
1	5	82.6419220	2.183319
1	6	81.8222656	2.832710
1	7	83.3060913	3.475544
1	8	87.0358887	3.475544
2	1	81.6638947	2.183319
2	2	84.0998688	2.183319
2	3	80.8118896	2.183319
2	4	80.1779175	2.183319
2	5	82.8759003	2.183319
2	6	82.7522583	2.832710
2	7	78.2811127	3.475544
2	8	81.5359192	2.475544
3	1	81.2319031	2.183319
3	2	81.5559235	2.183319
3	3	78.7239227	2.183319
3	4	83.1859131	2.183319
3	5	77.7579498	2.183319
3	6	77.0256500	2.832710

APPENDIX E

Continued

Method	Trial	Mean	Standard Error
3	7	85.5511169	2.183319
3	8	78.5609131	3.475544
4	1	79.6399384	2.183319
4	2	77.7079468	2.183319
4	3	81.1119232	2.183319
4	4	76.5359650	2.183319
4	5	80.5539551	2.183319
4	6	73.9523315	2.832710
4	7	78.7111511	3.475544
4	8	80.7609558	3.475544
5	1	80.3039398	2.183319
5	2	80.3699493	2.183319
5	3	78.0439453	2.183319
5	4	77.8239594	2.183319
5	5	78.1559753	2.183319
5	6	77.0390015	2.832710
5	7	76.5111694	3.475544
5	8	81.0559235	3.475544
6	1	81.3239136	2.183319
6	2	80.0979156	2.183319
6	3	81.5439148	2.183319
6	4	80.5859375	2.193319
6	5	81.0319366	2.183319

APPENDIX E

Continued

Method	Trial	Mean	Standard Error
6	6	77.3789673	2.832719
6	7	75.1311340	3.475544
6	8	79.2609253	3.475544
7	1	79.4419350	2.193319
7	2	81.2659302	2.183319
7	3	76.0159302	2.183319
7	4	78.5839386	2.183319
7	5	81.1479492	2.183319
7	6	80.1656342	2.832710
7	7	78.5361328	3.475544
7	8	81.4159546	3.4775544
8	1	81.5738220	2.183319
8	2	81.8278503	2.183319
8	3	78.6878662	2.183319
8	4	79.5098724	2.183319
8	5	79.9518890	2.193319
8	6	78.6555481	2.832710
8	7	81.2610626	3.475544
8	8	79.9856110	3.475544

APPENDIX F

Means and Standard Errors
For Oxygen Percent For
Methods By Trials

Method	Trial	Mean	Standard Error
1	1	16.8898926	0.114281
1	2	16.8878937	0.114281
1	3	16.8078918	0.114281
1	4	16.8018951	0.114281
1	5	16.8258972	0.114281
1	6	16.9576111	0.148273
1	7	16.6448669	0.181920
1	8	16.8198700	0.181920
2	1	16.7318031	0.114281
2	2	16.8658905	0.114281
2	3	16.8518982	0.114281
2	4	16.8358917	0.114281
2	5	16.9078979	0.114281
2	6	16.8542938	0.148273
2	7	16.5798645	0.181920
2	8	16.7298279	0.181920
3	1	16.7498932	0.114281
3	2	16.5898895	0.114281
3	3	16.4678955	0.114281
3	4	16.7138824	0.114281
3	5	16.6959076	0.114281
3	6	16.8076172	0.148273

APPENDIX F

Continued

Method	Trial	Mean	Standard Error
3	7	16.8248596	0.181920
3	8	16.6098480	0.181920
4	1	16.7778931	0.114281
4	2	16.6778870	0.114281
4	3	16.7318878	0.114281
4	4	16.7858734	0.114281
4	5	16.7079010	0.114281
4	6	16.7676086	0.148273
4	7	16.5448608	0.181920
4	8	16.6848450	0.181920
5	1	16.7499084	0.114281
5	2	16.5498962	0.114281
5	3	16.4438934	0.114281
5	4	16.7558899	0.114281
5	5	16.8339081	0.114281
5	6	16.6942902	0.148273
5	7	16.5698853	0.181920
5	8	16.3148651	0.181920
6	1	16.8699036	0.114281
6	2	16.8558960	0.114281
6	3	17.0418854	0.114281
6	4	17.0118866	0.114281
6	5	17.0198975	0.114281

APPENDIX F

Continued

Method	Trial	Mean	Standard Error
6	6	17.0142822	0.148273
6	7	16.6948547	0.181920
6	8	16.9798431	0.181920
7	1	17.0419006	0.114281
7	2	17.0018921	0.114281
7	3	17.0338898	0.114281
7	4	17.0738831	0.114281
7	5	17.0839081	0.114281
7	6	17.1209412	0.148273
7	7	17.0498657	0.181920
7	8	17.0548248	0.181920
8	1	16.8377838	0.114281
8	2	16.9038086	0.114281
8	3	17.0318146	0.114281
8	4	17.0118103	0.114281
8	5	17.1078339	0.114281
8	6	17.2008667	0.148273
8	7	16.7498016	0.181920
8	8	17.1545410	0.181920

APPENDIX G

Means and Standard Errors For
Carbon Dioxide Percent For
Method By Trial

Method	Trial	Mean	Standard Error
1	1	3.8699942	0.107117
1	2	3.6799955	0.107117
1	3	3.8699961	0.107117
1	4	3.9599953	0.107117
1	5	3.8199959	0.107117
1	6	3.9271555	0.138978
1	7	3.9434719	0.170516
1	8	4.0684586	0.170516
2	1	3.9199934	0.107117
2	2	3.7299948	0.107117
2	3	3.7899961	0.107117
2	4	4.0099945	0.107117
2	5	3.7699957	0.107117
2	6	3.9938221	0.138978
2	7	3.9934711	0.170516
2	8	4.0684605	0.170516
3	1	3.9299927	0.107117
3	2	3.8699932	0.107117
3	3	4.2399931	0.107117
3	4	4.1799927	0.107117
3	5	3.8899946	0.107117
3	6	4.0438213	0.138978

APPENDIX G

Continued

Method	Trial	Mean	Standard Error
3	7	3.8184710	0.170516
3	8	4.1434584	0.170516
4	1	3.9199934	0.107117
4	2	3.8099947	0.107117
4	3	3.9199953	0.107117
4	4	3.9999952	0.107117
4	5	3.8699951	0.107117
4	6	4.0771561	0.138978
4	7	4.0684710	0.170516
4	8	4.1184607	0.170516
5	1	3.9799919	0.107117
5	2	3.9799929	0.107117
5	3	4.0799942	0.107117
5	4	3.9999943	0.107117
5	5	3.8999939	0.107117
5	6	4.0771542	0.138978
5	7	4.1184683	0.170516
5	8	4.3934574	0.170516
6	1	3.9099941	0.107117
6	2	3.7699947	0.107117
6	3	3.7999964	0.107117
6	4	3.9999952	0.107117
6	5	3.7899952	0.107117

APPENDIX G

Continued

Method	Trial	Mean	Standard Error
6	6	4.0271559	0.138978
6	7	3.9184723	0.170516
6	8	3.9934597	0.170516
7	1	3.9199934	0.107117
7	2	3.6999941	0.107117
7	3	3.8799953	0.107117
7	4	3.9599943	0.107117
7	5	3.7999954	0.107117
7	6	3.9604883	0.138978
7	7	3.8184719	0.170516
7	8	4.0434599	0.170516
8	1	3.8799896	0.107117
8	2	3.8199892	0.107117
8	3	3.8499899	0.107117
8	4	3.9399910	0.107117
8	5	3.8099918	0.107117
8	6	3.9604874	0.138978
8	7	3.9434710	0.170516
8	8	3.9684420	0.170516

APPENDIX H

Means and Standard Errors
For Respiratory Quotient
For Method by Trial

Method	Trial	Mean	Standard Error
1	1	0.9552155	0.032726
1	2	0.9085357	0.032726
1	3	0.9370155	0.032726
1	4	0.9597558	0.032726
1	5	0.9269560	0.032726
1	6	0.9873062	0.042460
1	7	0.9189450	0.052096
1	8	0.9956948	0.052096
1	9	0.9631926	0.073711
2	1	0.9310156	0.032726
2	2	0.9158757	0.032726
2	3	0.9281155	0.032726
2	4	0.982556	0.032726
2	5	0.9339759	0.032726
2	6	0.9796731	0.042460
2	7	0.9188449	0.052096
2	8	0.9747950	0.052096
2	9	0.9900926	0.073711
3	1	0.9372555	0.032726
3	2	0.8914359	0.032726
3	3	0.9510955	0.032726
3	4	0.9878754	0.032726

APPENDIX H

Continued

Method	Trial	Mean	Standard Error
3	5	0.9150160	0.032726
3	6	0.9830064	0.042460
3	7	0.9264451	0.052096
3	8	0.9634951	0.052096
3	9	1.0790882	0.043711
4	1	0.9400354	0.032726
4	2	0.8943158	0.032726
4	3	0.9354355	0.032726
4	4	0.9623588	0.032726
4	5	0.9129559	0.032726
4	6	0.9823729	0.042460
4	7	0.9268451	0.052096
4	8	0.9788947	0.052096
4	9	0.9716928	0.073711
5	1	0.9486554	0.032726
5	2	0.9052358	0.032726
5	3	0.9089156	0.032726
5	4	0.9562359	0.032726
5	5	0.9541558	0.032726
5	6	0.9707062	0.042460
5	7	0.9459451	0.042096
5	8	0.9662949	0.052096
5	9	0.9722929	0.073711

APPENDIX H

Continued

Method	Trial	Mean	Standard Error
6	1	0.9627354	0.032726
6	2	0.9249355	0.032726
6	3	0.9783553	0.032726
6	4	1.0217752	0.032726
6	5	0.9678155	0.032726
6	6	1.0295057	0.042460
6	7	0.9265449	0.052096
6	8	1.0165434	0.052096
6	9	1.0999861	0.073711
7	1	1.0097141	0.032726
7	2	0.9396949	0.032726
7	3	1.0062742	0.032726
7	4	1.0266333	0.032726
7	5	0.9849948	0.032726
7	6	1.0409040	0.042460
7	7	0.9855438	0.052096
7	8	1.0430937	0.052096
7	9	1.0212879	0.073711
8	1	0.9470142	0.032726
8	2	0.9466540	0.032726
8	3	0.9915728	0.032726
8	4	1.0079699	0.032726
8	5	0.9990532	0.032726

APPENDIX H

Continued

Method	Trial	Mean	Standard Error
8	6	1.0591669	0.042460
8	7	0.9422432	0.052096
8	8	1.0548401	0.052096
8	9	1.0384655	0.073711

APPENDIX I

Means and Standard Errors For Time
For Method By Trial

Method	Trial	Mean	Standard Error
1	1	102.9999084	17.285522
1	2	92.9999237	17.285522
1	3	103.9999237	17.285522
1	4	90.5998383	17.285522
1	5	87.0000000	17.285522
1	6	81.1799011	22.436804
1	7	100.2981720	27.516174
1	8	95.2976379	27.516174
2	1	80.0001831	17.285522
2	2	97.9999237	17.285522
2	3	118.9996948	17.285522
2	4	110.5997467	17.285522
2	5	104.9999084	17.285522
2	6	66.8468170	22.426804
2	7	80.2981567	27.516174
2	8	82.7975769	27.516174
3	1	96.9999084	17.285522
3	2	89.9999390	17.285522
3	3	48.0001984	17.285522
3	4	103.9997711	17.285522
3	5	83.9999847	17.285522
3	6	91.8465271	22.426804

APPENDIX I

Continued

Method	Trial	Mean	Standard Error
3	7	132.7978058	27.516174
3	8	90.2978516	27.516174
4	1	130.9997711	17.285522
4	2	112.9998322	17.285522
4	3	120.9998322	17.285522
4	4	94.1999512	17.285522
4	5	102.9998932	17.285522
4	6	93.5130920	22.426804
4	7	142.7976532	27.516174
4	8	97.7976685	27.516174
5	1	104.4001160	17.285522
5	2	79.0002441	17.285522
5	3	50.0003815	17.285522
5	4	91.6002350	17.285522
5	5	52.4003906	17.285522
5	6	95.1800537	22.426804
5	7	85.2983551	27.516174
5	8	92.7980804	27.516174
6	1	80.9999847	17.285522
6	2	99.9999237	17.285522
6	3	151.9998016	17.285522
6	4	100.4000854	17.285522
6	5	124.9998779	17.285522

APPENDIX I

Continued

Method	Trial	Mean	Standard Error
6	6	78.5131531	22.426804
6	7	102.7976685	27.516174
6	8	60.2977905	27.516174
7	1	103.9999084	17.285522
7	2	110.9999237	17.285522
7	3	89.9999542	17.285522
7	4	106.0001526	17.285522
7	5	90.9999542	17.285522
7	6	109.1797791	22.426804
7	7	136.2975464	27.516174
7	8	140.2976532	27.516174
8	1	111.9993744	17.285522
8	2	96.9996185	17.285522
8	3	107.9996185	17.285522
8	4	74.9997101	17.285522
8	5	106.9996338	17.285522
8	6	111.8461304	22.426804
8	7	162.7973022	27.516174
8	8	102.7977448	27.516174

A COMPARISON OF METABOLIC MEASUREMENT TECHNIQUES

by

ROBERT W. ALBRIGHT

B.A., Duke University, 1974

AN ABSTRACT OF A MASTER'S THESIS

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KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

The purpose of this study was to examine three techniques of measurement of oxygen uptake for consistency of measurement. Oxygen uptake measures were determined by a Douglas Bag method, Mini Bag method and Tissot Tank method for five male subjects exercising at steady state. Expired air was collected by each technique for 30, 60 and 120 seconds and $\dot{V}O_2$ was determined. The Tissot Tank's capacity did not allow 120 second samples to be obtained. All subjects were well trained males who ran 25 to 30 miles a week regularly. Each set of data required 20 minutes of steady state running by each subject. Five sets of data were obtained from each subject. The data was analyzed by method and trial by the Two Way Analysis of Variance. When significant differences were found the Fisher technique of least significant differences was used to locate the differences. The results obtained found the $\dot{V}O_2$'s measured by the Tissot Tank were significantly lower than all other techniques with the exception of the Douglas Bag 120 second sample. Significant differences were also found among trials. Oxygen uptake was found to increase regularly from the collection of trial one to trial eight. This meant that each subject fatigued through the exercise bout. Respiratory quotient reflected this fatigue as it increased from the measurement of trial one to trial eight demonstrating the decrease in efficiency. Assuming that each subject was in fact not at steady state, the differences found in oxygen uptake measures leaves these results inconclusive when considering consistency of measurement.