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A COMPARISON OF MAXIMUM OXYGEN UPTAKE DETERMINATION BY BICYCLE ERGOMETERY AT VARIOUS PEDALLING FREQUENCIES AND BY TREADMILL RUNNING AT VARIOUS SPEEDS

by

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ABSTRACT

Five male, university athletes (Age 24.8 yr, Weight 80 kg, Height 184 cm, PWC170 1563 kgm/min) were tested for maximum oxygen uptake during bicycling at pedalling frequencies of 60, 80, 100 and 120 rpm and during inclined treadmill running at speeds of 6.0, 6.5, 7.0 and 7.5 mph. Maximal oxygen uptake was 10.5% lower in bicycle ergometery than in treadmill running. Cycling at a pedalling frequency of 80 rpm elicited significantly greater maximal oxygen uptake than at 60 or 120 rpm. Speed of running had no significant effect on maximal oxygen uptake during treadmill testing. Significant differences between bicycle ergometery and treadmill running at exhaustion were also found in the following parameters: heart rate ($p < 0.0005$), carbon dioxide production ($p < 0.0005$) and ventilatory equivalent ($p < 0.01$). Bicycle ergometery at various pedalling frequencies showed significant differences at exhaustion in: expired ventilation which was less at 60 rpm than at 80 rpm and 100 rpm ($p < 0.05$), ventilatory equivalent which was greater at 100 rpm than at 80 rpm ($p < 0.025$) and 60 rpm ($p < 0.01$). Significant differences at exhaustion in treadmill running at various speeds were shown in carbon dioxide production which was less at 7.5 mph than at 7.0, 6.5 ($p < 0.025$ and 6.0 mph ($p < 0.005$), and less at 7.0 mph than at 6.5 ($p < 0.005$) and 6.0 mph ($p < 0.05$). Relative merits of bicycling versus treadmill running as tests of maximum aerobic capacity are discussed.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Maximum Oxygen Uptake: Criterion of Work Capacity

Maximum oxygen uptake (VO2max) is generally regarded as the best single physiological indicator of man's capacity for sustained muscular work. It is directly related to the maximal capacity of the cardiovascular—respiratory system to take up and transport oxygen to active tissues and for these tissues to use the oxygen. (Taylor et al., 1955, Åstrand, 1956, Balke and Ware, 1959, Hettinger et al., 1961).

Johnson (1946) indicated that "Quantitative assessment of physical fitness is one of the most complex and controversial problems in applied physiology. This situation arises in part from lack of agreement on what constitutes fitness for withstanding various types of stress and in part from lack of agreement on which measurements allow valid comparisons to be made among different individuals exposed to the same stress." Although he was referring to 'physical fitness' which is at best an all encompassing term, the same statement could quite suitably be applied to the measurement of VO2max.

Maximum oxygen uptake has been measured by many methods including treadmill, bicycle, hand cranking, ladder climbing, step tests, track running, swimming, rowing and by prediction from submaximal levels of exercise.

Several investigators (Appendix 21), have found motor driven treadmills and bicycle ergometers to be the most acceptable method for measuring individual maximum oxygen uptakes. This is supported by the large number of such measures reported in journals during the past 20 years.

Asmussen and Hemmingsen (1958), showed that 'aerobic capacity' in normal individuals is considerably lower in arm-work than in leg-work. Åstrand and Saltin (1961) showed that the mean oxygen uptake of a group determined by cycling (4.23 L/MIN) changed very little when the subjects were asked to cycle and crank with both their legs and arms (4.24 L/MIN) Thus it may be assumed that the muscle mass involved in cycling is not a limiting factor in obtaining a maximal measurement.

Treadmill vs. Bicycle Ergometer
Determination of VO2max

There have, however, been numerous studies which have consistently shown treadmill exercise to produce a greater VO2max than exercise on the bicycle ergometer. (Åstrand and Saltin, 1961, Glassford et al., 1965, Wyndham et al., 1966, Hermansen and Saltin, 1969, McArdle and Magel, 1970, Hermansen et al., 1970, Kamon and Pandolf, 1972, Miyamura and Honda, 1972, McArdle et al., 1973). These sources have shown bicycle ergometry to elicit maximum oxygen uptakes 5-10% smaller than those produced by the same individual treadmill running. One report however showed 7 of 55 subjects produced a higher VO2max in a bicycle ride than running on a treadmill (Hermansen and Saltin, 1969). Overall however, the mean difference seems 7% greater on the treadmill than on the bicycle.

Taguchi et al., (1971), in contrast to the studies already mentioned, compared bicycle ergometery at a pedal frequencies of 50 and 60 rpm with treadmill walking at 3.5 mph (Modified Balke Test) and found that there was no significant difference in the respective maximum oxygen uptakes.

Evaluation of VO2max is not only affected by the type of activity practiced in the test but also by the mode in which each component of the test is used viz: rate of pedalling (Åstrand and Saltin, 1961; Hermansen and Saltin, 1969; and Taguchi et al., 1971), upright versus supine pedalling (Miyamura and Honda, 1972), constant loading versus incremental loading (Miyamura and Honda, 1972), incremental loading on one day compared with that on successive days (Glassford et al., 1965), intermittent versus continuous treadmill running (Wyndham et al., 1966, McArdle et al., 1973) and level treadmill running compared with grade running (Hermansen and Saltin, 1969).

Wyndham et al. (1966) stated that at high oxygen intake values, bicycle ergometry seriously and significantly underestimates VO2max compared to the treadmill. Bicycle ergometry however, has many distinct advantages over the treadmill (Åstrand, P.O., 1952, Hermansen et al., 1970) including such items as portability, ease of regulating the work rate and safety. If a mode of testing could be found using the bicycle ergometer which would ensure correspondence of VO2max values to those on the treadmill, it would be useful.

In the majority of the studies cited, the pedalling frequencies have been low i.e., 50 rpm (Hettinger et al., 1961, Michael and Horvath, 1965, Hermansen and Saltin 1969, Nagle et al., 1971, Taguchi et al., 1971), 60 rpm (Hermansen and Andersen, 1965, Hermansen and Saltin 1969, Taguchi et al., 1971, Kamon and Pandolf, 1972, Miyamura and Honda, 1972) or 70 and 80 rpm (Hermansen and Saltin, 1969).

These lower pedalling rates correspond closely with the guide lines set down by the Research Committee of the International Council of Sport and Physical Education on Standardization of Ergometry, during the XVI International Congress of Sports Medicine. (Larson, 1966)

TABLE 1

PROPOSED SPEED OF PEDALLING FOR DIFFERENT POWER OUTPUTS (INTERNATIONAL CONGRESS OF SPORTS MEDICINE, HANOVER, 1966)

0 - 600	kgm/min.	30 (25 - 35) revolutions/min.
600 - 1200	kgm/min.	40 (35 - 45) revolutions/min.
1200 - 1800	kgm/min.	50 (45 - 55) revolutions/min.
> 1800	kgm/min.	60 (55 - 65) revolutions/min.

Banister and Jackson (1967), demonstrated that oxygen uptake measured at low power output developed at high pedalling frequencies combined with small brake resistance was equivalent to that at much higher power output developed at slower pedalling frequency and higher brake resistance. Thus it may be possible to conduct tests on the same individual at high pedalling rates i.e., 100 - 120 rpm, and medium brake resistance and obtain comparable VO2max measures to those obtained by various modes of testing on the treadmill.

It has been common practice for investigators using bicycle ergometry to keep the pedalling rate constant (usually 50-60 rpm) and gradually increase the load until the subject reaches exhaustion. In treadmill testing the most accepted method sets a constant speed against a gradually increasing imposed gradient. There are however, studies in which the grade was held constant and an increasing work rate was imposed by increasing the speed of the treadmill (Wyndham et al., 1966, Miyamura and Honda, 1972). In the former study, a continuous treadmill running test set the treadmill speed at 4.5 mph and every 2 minutes the speed was increased by 0.5 mph until exhaustion. Miyamura and Honda (1972) however, required their subjects to run at 150-170 m/min (6mph) for the first 2 minutes and increased the rate by 10 m/min (0.375 mph) once every minute until exhaustion.

Lactate in Maximal Exercise

Anderson et al. (1971) indicated that a blood lactate value of over 100 mg/100 ml is a good subsidiary criterion that the VO2max for an individual has been reached.

Bang (1936), indicated that at greater working intensities, blood lactates are higher and for very severe work maximal vlaues are attained only after the cessation of work during recovery.

Edwards et al, (1973), while studying the cardiorespiratory and metabolic costs of continuous and intermittent exercise in man, found that during exercise, lactate concentration in muscle water was higher ($p < 0.05$) than in blood water.

Karlsson (1971), found it reasonable to conclude that a close correlation exists between maximal muscle lactate concentration and the perception of exhaustion during brief maximal concentric leg exercise and that muscle lactate concentration or changes secondary to its elevation are directly or indirectly responsible for muscular fatigue. He also found a close linear relationship between the highest blood lactate concentration and the muscle lactate concentration obtained immediately after cessation of work. Reduction of muscle lactate concentration after maximal exercise seems to approach resting values asymptotically whereas blood concentration typically shows a peak elevation 10 minutes postexercise. (Diamant et al., 1968).

Karlsson (1971) noted no marked increase in lactate concentration until work rate exceeded 50 - 60% of VO2max. Hermansen and Stensvold (1972), found that most trained subjects showed no marked increase in blood lactate concentrations during continuous running at work rates ranging from 30 to 90% of their VO2max. This indicates that individual critical work rate levels exist beyond which a pronounced increase in the lactate production may occur.

Bang (1936) found that the blood lactate concentration tended to decrease if the work were continued for longer than 10 minutes. Blood lactate concentrations also show a decrease at standardized work rates which are preceeded by prolonged work (Karlsson, 1971). The most reasonable explanation of these findings is that in the course of the work itself part of the lactate produced in the exercising muscles may have been used as a substrate in different tissues of the body. (Rämmel and Ström, 1949, Jorfeldt, 1970).

Karlsson (1971) found no significant difference in resting lactate concentration between trained and untrained subjects. Following exhaustive work rates there was significant difference ($p < 0.001$) in muscle lactate concentration of trained (22.7 mM/kg wet muscle) and untrained subjects (16.9 mM/kg wet muscle). However,the difference in the blood lactate concentration levels between the two groups was less (14.6 and 12.3 mM/l. respectively) than might have been expected from muscle lactate concentration.

Margaria et al. (1963) assumed that lactic acid freely and rapidly diffuses uniformily in all the water of the body. Karlsson (1971) indicated that equal concentrations in muscle and blood existed 10 minutes after the work stopped. Kübler et al. (1966) and Hirsche, Langohr and Wacker (1970) showed that the lactic acid translocation process was evidently not simple diffusion and Kübler et al., postulated that an active transport system might be involved.

Criterion Lactate Measurement:

Timing After Exercise

Margaria et al. (1963) took blood samples at 1, 3, 5, 8, 15, and 30 minutes following exhaustive exercise and found that the lactate concentration levels tended to increase after exercise for the first 5 - 8 minutes.

Other investigators took a blood sample at 1 and 3 minutes (Åstrand _et al._, 1963), the 3rd and 5th minute (Margaria _et al._, 1964), 4 to 5 minutes (Di Prampero _et al._, 1973), 5 minutes (Newton, 1963) and 5 to 6 minutes (Kasch _et al._, 1973) post exercise to determine the blood lactate concentration level. These variations in the timing of drawing blood samples for determining lactate concentrations exemplify the problem of obtaining a peak lactate concentration from blood samples.

Shephard _et al._ (1968) took blood samples from a heated finger tip at 2 and 4 minutes post exercise. They found that in 13 subjects, 2-minute lactate concentrations were up to 8 mg/100 ml higher than in 4 minute samples, in 2 subjects the mean readings were identical, and in 9 of the subjects the 4-minute readings were up to 8 mg/100 ml higher. These results appear to be in disagreement with those of Margaria _et al._ (1963).

Hermansen and Saltin (1969) attempted to find a solution to the problem of blood sampling timing. They took 2 or 3 blood samples during the first 10 minutes of recovery in order to secure the peak lactic acid value.

This experiment intends to compare the equivalence of VO2max determinations performed both by bicycle ergometry and treadmill running by using a mode of bicycle ergometry (high pedal frequency) which ensures maximal inefficiency of external work delivery and thus maximal involvement of the human cardio-respiratory system.

The tests used in this experiment included variations in 1) pedalling frequency on the bicycle ergometer and 2) running speed on the treadmill. Each exhaustive test was completed in one session with a triangular format of increasing work rates, i.e., work rates were increased at prescribed time intervals during each test.

Hypotheses:

1. At higher pedalling frequencies (> 60 rpm) on the bicycle ergometer, the VO2max of an individual will approach those values obtained on the treadmill.

2. At the faster speeds of treadmill running with an identical sequence of increasing slopes, the VO2max of an individual will be greater.

CHAPTER II

MATERIALS AND METHODS

Subjects

Subjects were chosen from a group of volunteer athletes on the basis of their performance on a PWC170 test. Subjects chosen were those who obtained a PWC170 greater than 1300 kgm/min which is above the 90th percentile for Canadian adults (Métivier and Orban, 1970). Thus any differences in oxygen uptake between exhaustive tests would be more likely due to the method of testing rather than an improvement in the physical fitness of the subject, although additional precautions against the latter occuring were also taken.

Each subject, prior to involvement in the experiment, was required to have a medical examintation by his family physician and present a medical form signed by his physician stating that he was fit enough to participate in the study.

The subjects were given an outline of both the experiment and their responsibilities of the subjects. They were, upon volunteering, required to sign a consent form and to fill out a questionaire dealing with their past and present athletic training. Pertinent data on the subjects is given in Table 2.

Adaptive Training

Prior to testing, each subject attended six training sessions where he was introduced to the laboratory environment, the equipment and some of the procedures to be used in the exhaustive testing. These sessions alternated between bicycle riding and treadmill running and in each session various combinations of pedalling speed and load or running speed and grade were experienced by the subject. At least once during each session the subject exercised at a maximal or supramaximal workload for a short period of time to accustom him to the supreme effort that would be necessary for the exhaustive tests. It was assumed that these adaptive sesssions would be sufficient to negate any appreciable learning factor that may have otherwise occurred during the course of the exhaustive testing series and increased fitness (VO2max) at the end of the investigative period was specifically tested for.

In the sixth training session the subject was again given a PWC170 test as a check on the validity of the initial test. The results of the PWC170 tests and pertinent data on the subjects are shown in Table 2.

Table 2 Vital statistics of subjects

Subj.	Age (yrs)	Weight (kg)	Height (cm)	PWC170 (kgm/min)	PWC150 (kgm/min)	VO2max (l/min)
VP	23.5	97.0	197.0	1515	1230	4.2
MC	32.0	79.3	183.1	1630	1380	4.9
BN	28.7	77.1	179.3	1645	1370	4.8
BC	21.4	76.0	184.1	1615	1335	4.7
JH	18.5	70.5	176.8	1410	1170	4.1

1. PWC170 is an average of two tests.
2. Maximum oxygen uptake (VO2max) is estimated from submaximal work loads (I. Åstrand, 1960).

Warm-up

Prior to each test the subject was given a standard six minute warm-up on the bicycle ergometer at a pedalling rate of 60 rpm. The first minute of the warm-up was done with no load imposed (zero workload). During the next five minutes a load, predicted to elicit a heart rate of 150 beats per minute was imposed. The load to be used was estimated from the subject's results on the PWC170 test. The warm-up was the same for all tests for each individual, in order to avoid any infuluence of warm-up on the results of the various exhausive tests.

An expired gas sample was collected during the last minute of warm-up and ventilation and heart rate were recorded for each minute of the warm-up. A blood sample was drawn as soon as possible, within the 2 minutes after the completion of each warm-up.

Exhaustive Testing

Each subject completed a series of nine exhaustive tests: four on the bicycle ergometer, four on the treadmill together with a repeat of the first test performed in the series. Five testing sequences (A to E) (Table 3) were developed using a table of random numbers, with the condition that bicycle and treadmill tests would be alternatively administered. The sequences were randomly assigned to the five subjects, using a table of random numbers.

Subjects performed a maximum of two exhaustive tests per week with a minimum of two days rest between tests. All testing was done in the Human Performance Laboratory (Simon Fraser University) between 9:00 and 11:00 a.m. and subjects were instructed to have only a light breakfast prior to testing sessions.

The subjects reported first to the laboratory to be weighed (shorts and socks), then to the S.F.U. Health Services to have a catheter inserted in the forearm (See 'Blood') and then returned to the laboratory for the testing session.

TABLE 3

Testing sequences for subjects (above) and equipment and mode of testing (below).

Order	Tests									Subj
A	6	4	8	1	7	3	5	2	6	VP
B	1	5	4	7	2	6	3	8	1	MC
C	4	8	3	6	1	5	2	7	4	JH
D	8	3	7	2	5	4	6	1	8	BC
E	5	2	6	3	8	1	7	4	5	BN

Test #	Apparatus	Speed
1	Bicycle	60 rpm
2	Bicycle	80 rpm
3	Bicycle	100 rpm
4	Bicycle	120 rpm
5	Treadmill	6.0 mph
6	Treadmill	6.5 mph
7	Treadmill	7.0 mph
8	Treadmill	7.5 mph

i. Bicycle Ergometery

A Monarch bicycle ergometer (Varberg, Sweden), used for all bicycle tests, was placed on the treadmill (set at zero grade) to maintain consistancy in the testing environment. Each subject was tested at four different pedalling speeds: 60, 80, 100, and 120 rpm. For each test, the first two workloads were maintained for one minute each. Subsequently workloads were increased every two minutes or until exhaustion was reached. Table 4 shows increasing power outputs throughout the tests for various combinations of pedal frequency and load. Exhaustion was defined as the point in the test at which the required pedalling frequency could no longer be maintained. Subsidiary criteria for exhaustion were a blood lactate level of over 80 mg/100 ml (P.-O. Åstrand, 1952; I. Åstrand, 1960; Rodahl and Issekutz, 1962) and a heart rate of over 180 beats per minute.

TABLE 4

Progression of work rates at various conbinations of pedalling frequency and load for each minute of exhaustive bicycle testing

TIME (min)	WORK RATE (kgm/min)	LOAD IMPOSED (RPM) (60)	(80)	(100)	(120)
1	900	2.5	1.9	1.5	1.3
2	1200	3.3	2.5	2.0	1.7
3 & 4	1500	4.2	3.1	2.5	2.1
5 & 6	1800	5.0	3.8	3.0	2.5
7 & 8	2100	5.8	4.4	3.5	2.9
9 & 10	2400	6.7	5.0	4.0	3.3

ii. Treadmill Running

An electrically driven treadmill (Model 24-72, Quinton, Seattle, Washington) was used for all the treadmill tests. Each subject was tested at four different running speeds: 6.0, 6.5, 7.0, and 7.5 mph. The first minute of each test was run on the level and at the end of each minute the grade was increased by 2.5% until exhaustion (Maksud and Coutts, 1971 (7 mph); McArdle et al, 1973 (6 mph)). Exhaustion was defined as that point in the test at which the subject could no longer keep up with the treadmill or had to use the hand rails for support. The subsidiary criteria were the same as for the bicycle tests.

Heart Rate

Heart rates were recorded on an electrocardiograph (Overseas, Model SCC 1A) during the last ten seconds of each minute of warm-up, exhaustive exercise and five minutes of recovery. Heart rates were also taken prior to the start of warm-up and exhaustive exercise. A modified C5 bipolar transthoracic ECG lead was used for this purpose.

Ventilation

The subjects breathed through a triple-J low resistance valve (Colins, Boston, Mass.) which was connected in series by non-kinkable hose (I.D. 1.5 inches), to a Parkinson-Cowan, low resistance ventilation meter, a three way valve and meteorological balloons.

Expiratory gas volumes were metered for each minute of warm-up, exercise and recovery. The temperature of the expired gas for each minute was determined from a thermometer introduced into the air tight system proximal to the ventilation meter.

The barometric pressure and ambient temperature were recorded prior to and following each test. Averages of the readings were used in calculating ventilation (BTPS) and oxygen uptake.

Oxygen Uptake

One minute expired gas samples were collected in meteorological balloons during the sixth minute of warm-up and the last two minutes of exercise using the Douglas Bag technique. Gas samples from each of the balloons, were drawn immediately following the test, into two 50 c.c. oiled glass syringes (S9528, London-Luer, American Hospital Supply). Duplicate analyses (difference < 0.05%) for oxygen and carbon dioxide content of the samples were done by the micro-Scholander technique (Scholander, 1947).

A PL/1 computer program was written to calculate the oxygen uptake (l/min and ml/kg/min), the carbon dioxide produced (l/min), the respiratory exchange ratio, the ventilatory equivalent and the percentage oxygen extraction from the test data for each expired gas sample examined. The program and a sample output are shown in Appendices 15 and 16.

Blood

Prior to each test, the subject had a butterfly catheter (No. 4550, Abbot Laboratories, North Chicago, Ill.) inserted in a subcutaneous vein in the forearm for the purpose of obtaining blood samples at various points during the test. Samples (3 ml each) were drawn as soon as possible following warm-up and at the fifth and eighth minute of recovery following exhaustive exercise.

i. Hemoglobin

Hemoglobin concentration was analyzed in a colorimeter Hb-meter (No.1010 C, American Optical, Buffalo, New York).

ii. Hematocrit

The hematocrit was determined by means of an Adams Readocrit micro-hematocrit centrifuge.

iii. Lactate Concentration

One ml of blood was deproteinized with two ml of ice-cold perchloric acid (0.6 N) in a centrifuge tube and centrifuged for ten minutes at 3000 rpm (HN-S Centrifuge, International Equipment Co., Mass., USA). The supernatant was then pipetted into a clean centrifuge tube and again centrifuged for ten minutes. The supernatant was transferred to a clean test tube and refrigerated until analysis could be done.

Analysis of serum lactate concentration was done by a Boehringer Mannheim Lactate Kit (No. 15972) using the spectrophotometric Boehringer Mannheim enzymatic method (Hohorst, 1965). The spectrophotometer used was a Spectronic 70 (Bausch and Lomb) and at least duplicate analysis was done on each sample.

Statistical Analysis

Statistical analysis of the results was accomplished on an IBM 370/155 in Simon Fraser University Computing Center. An integrated system of computer programs, "Statistical Package for the Social Sciences" (SPSS)(Nie et al, 1973), was used for the storage, file manipulation, data transformation and basic statistical analysis of the data. A sample of the SPSS program and output is shown in Appendices 17 and 18.

Two way analysis of variance of all parameters used a

BMD08V program from "BMD Biomedical Computer Programs"(Dixon, 1973). A crossed randomized partial hierachal design (CRPH-52(4)) (Kirk, 1968) was used with the following linear equation:

$$\chi_{ijkm} = \mu + \alpha_i + \beta_j + \gamma_{k(j)} + \alpha\beta_{ik(j)} + \xi_{m(ijk)}$$

Significant F values for the effects of tests nested within equipment, were further analysed by paired-t tests.

CHAPTER III

RESULTS

Individual heart rates, ventilation, respiratory gas exchange, and blood chemistry for each subject during warm-up and exhaustive exercise for all sessions are shown in appendices 3 through 14.

Test Conditions

Subjects VP, MC and BN were tested during the months of May through July while subjects BN and JH were tested during September and October. The first two subjects (VP, MC) took 50 and 43 days respectively from start to finish of the program of tests while the last three (BN, BC and JH) took only 32, 28 and 29 days respectively.

All tests were done in the same test area where the mean barometric pressure was 736 mm Hg with a range of 727 to 742 mm Hg and the mean ambient temperature was 22.4 C with a range of 20.8 to 25.8 °C (Table 5).

Analysis of variance showed no significant difference in the ambient temperature within or between bicycle and treadmill tests during the study.

TABLE 5

TEST CONDITIONS: Mean and standard error for subjects' weight (WGT, kg), barometric pressure (BP, mm Hg), ambient temperature (TEMP, C), warm-up oxygen uptake (WUMK, ml/kg/min), time to exhaustion (TIM, min) and final work rate (FWR, kgm/min [bicycle], % grade [treadmill]) for five male subjects at the pedalling frequencies and running speeds shown in the left-hand column.

TEST	WGT	BP	TEMP	WUMK	TIME	FWR
60 RPM	79.97	736.8	21.8	40.8	8.60	2182
	4.48	0.7	0.2	1.9	0.40	92.5
80 RPM	79.61	738.3	22.1	41.7	8.40	2280
	4.50	1.1	0.4	2.1	0.29	75.7
100 RPM	79.86	733.9	22.2	41.4	7.90	2191
	4.39	2.4	0.3	2.1	0.51	93.1
120 RPM	80.11	734.2	23.2	41.5	6.32	1881
	4.65	2.0	0.8	1.6	0.63	79.3
BIKE	79.89	735.8	22.3	41.4	7.81	2134
	2.07	0.9	0.3	0.9	0.30	52.3
6.0 MPH	80.02	736.4	23.1	40.3	8.86	20.0
	4.51	1.1	0.7	1.8	0.62	1.8
6.5 MPH	80.02	735.8	22.4	40.9	8.04	18.5
	4.19	0.8	0.5	1.7	0.60	1.7
7.0 MPH	79.60	738.3	21.8	41.7	7.48	16.5
	4.36	0.9	0.3	1.8	0.61	1.3
7.5 MPH	80.12	733.5	22.8	40.4	6.72	15.5
	4.55	2.1	1.0	2.0	0.56	1.7
TREAD-MILL	79.94	736.0	22.5	40.8	7.78	17.6
	2.02	0.7	0.3	0.8	0.33	0.8
ALL	79.91	735.9	22.4	41.1	7.79	
	1.43	0.6	0.2	0.6	0.22	

Analysis of the barometric pressure showed no difference between the bicycle and treadmill tests. There was, however, a difference ($p < 0.1$) in barometric pressure within the bicycle tests.

Warm—up

The warm-up for subjects VP, MC, BN, BC, AND JH were completed with frictional resistances of 3.75, 3.9, 3.9, 3,8 and 3.3 kp respectively and a mean pedal frequency of 61 (SE 0.15) rpm.

The mean and standard error for heart rate and ventilation for each minute of warm-up are given in table 6. Mean pooled warm-up heart rates prior to exhaustive exercise for bicycle and treadmill tests were 145 (SE 1.2) and 145 (SE 0.8) beats per minute respectively. The mean and standard error for warm-up ventilation, was 97.9 (SE 2.8) and 97.7 (SE 2.8) l/min for bicycle and treadmill respectively.

Warm-up gas analysis for different tests are shown in table 7. The mean oxygen uptakes prior to exhaustive testing on the bicycle and treadmill were 3.273 (SE 0.040) and 3.235 (SE 0.037) l/min respectively and were significantly different ($p < 0.05$) from each other.

TABLE 6

WARM-UP: Mean and standard error for heart rate (bpm) and ventilation (BTPS, L/MIN) for five male subjects for the second through the sixth minute of warm-up prior to exhaustive exercise at various pedal frequencies and running speeds shown in the left-hand column.

TEST	HEART RATE					VENTILATION				
	2	3	4	5	6	2	3	4	5	6
60 RPM	128	135	139	141	143	46.7	82.5	90.3	93.9	95.2
	0.4	0.7	1.4	1.0	2.3	2.0	4.6	4.5	4.9	5.1
80 RPM	130	137	142	144	147	49.3	81.8	93.1	95.6	98.7
	1.9	1.9	1.5	1.6	1.9	1.6	4.4	4.7	5.7	6.3
100 RPM	131	138	140	143	145	51.7	81.1	90.8	93.5	97.0
	1.6	1.7	1.6	1.9	1.4	4.1	3.7	4.7	6.1	5.7
120 RPM	129	137	140	141	144	54.5	82.6	94.3	97.2	100.7
	1.3	1.9	2.7	3.5	3.6	4.3	4.9	5.0	6.5	7.1
BIKE	129	137	140	142	145	50.4	82.0	92.1	95.1	97.9
	0.7	0.8	0.9	1.1	1.2	1.6	2.0	2.3	2.7	2.8
6.0 MPH	125	135	138	141	144	51.9	81.9	91.3	94.2	96.3
	5.3	2.6	2.4	2.9	2.0	3.4	4.4	4.6	5.4	5.1
6.5 MPH	128	138	139	143	145	49.9	84.2	93.6	98.4	99.4
	2.5	1.7	3.2	1.9	2.0	3.6	5.1	6.4	7.8	7.3
7.0 MPH	130	136	140	142	144	58.6	83.2	92.2	95.8	97.6
	1.4	3.4	1.3	1.9	1.4	6.8	4.5	4.8	5.4	6.4
7.5 MPH	129	138	141	144	146	53.0	80.5	90.3	93.3	97.6
	1.5	2.1	1.6	2.1	1.5	3.9	4.9	4.8	4.9	5.7
TREAD-MILL	128	137	139	142	145	53.4	82.4	91.8	95.4	97.7
	1.5	1.0	1.1	1.0	0.8	2.7	2.3	2.4	2.8	2.8
ALL	128	137	139	142	145	51.9	82.2	92.0	95.2	97.8
	0.8	0.6	0.7	0.7	0.7	1.4	1.5	1.7	1.9	2.0

TABLE 7

WARM-UP: Mean and standard error of respiratory gas exchange for five male subjects in the last minute of warm-up prior to exhaustive exercise at various pedal frequencies and running speeds shown in the left-hand column. Ventilation VENT (BTPS, L/MIN), Oxygen Uptake VO (STPD, L/MIN), Carbon Dioxide Expired (STPD, L/MIN), Respiratory Gas Exchange RER, Ventilatory Equivalent VE, Percentage Oxygen Extraction OE.

TEST	VENT	VO	VCO	RER	VE	OE
60 RPM	95.2	3.230	3.201	0.99	29.42	4.28
	5.1	0.059	0.152	0.03	1.19	0.18
80 RPM	98.7	3.289	3.273	1.00	29.96	4.21
	6.3	0.094	0.145	0.03	1.53	0.21
100 RPM	97.0	3.272	3.183	0.97	29.62	4.28
	5.7	0.096	0.140	0.03	1.44	0.20
120 RPM	100.7	3.301	3.321	1.00	30.37	4.17
	7.1	0.088	0.200	0.04	1.45	0.20
BIKE	97.9	3.273	3.244	0.99	29.84	4.24
	2.8	0.040	0.075	0.02	0.65	0.09
6.0 MPH	96.3	3.198	3.232	1.01	30.03	4.19
	5.1	0.069	0.138	0.03	1.07	0.16
6.5 MPH	99.4	3.248	3.298	1.01	30.52	4.16
	7.3	0.076	0.172	0.04	1.82	0.24
7.0 MPH	97.6	3.288	3.158	0.96	29.60	4.27
	6.4	0.071	0.155	0.03	1.58	0.22
7.5 MPH	97.6	3.207	3.247	1.01	30.38	4.17
	5.7	0.097	0.119	0.02	1.25	0.17
TREAD-MILL	97.7	3.235	3.234	1.00	30.13	4.20
	2.8	0.037	0.069	0.01	0.67	0.09
ALL	97.8	3.254	3.239	0.99	29.99	4.22
	2.0	0.027	0.050	0.01	0.46	0.06

Other respiratory parameters during the warm-up phase prior to exhaustive exercise, i.e., carbon dioxide production, respiratory gas exchange, ventilatory equivalent and oxygen extraction, were similar.

The mean warm-up blood lactate concentration, hemoglobin concentration and hematocrit prior to the eight tests were 44.1 (SE 2.7) mg/100 ml, 14.9 (SE 0.2) g/100 ml and 48.5 (SE 1.3) respectively and analysis of variance of these parameters detected no significant differences among tests.

Exhaustive Exercise

Mean heart rates and ventilation for each of the last five minutes of exhaustive exercise are shown in Table 8. Respiratory gas exchange variables are shown in Table 9.

i. Analysis of Variance: F-Ratios

Significant F values for differences between the results of exhaustive exercise on the bicycle and treadmill were shown in: Final heart rate ($p < 0.0005$, Bike (B)=183, Treadmill (TM)= 186), oxygen uptake ($p < 0.005$, B=4.624 l/min, TM=4.999 l/min), carbon dioxide production ($p < 0.001$, B=5.326 l/min, TM=5.852 l/min) and ventilatory equivalent ($p < .01$, B=39.45, TM=35.65) (Table 10).

TABLE 8

EXHAUSTIVE EXERCISE: Mean and standard error for heart rate (bpm) and ventilation (BTPS, L/MIN) for five male subjects from the last five minutes of exhaustive exercise at various pedal frequencies and running speeds shown in the left-hand column.

TEST	HEART RATES					VENTILATION				
	L-4	L-3	L-2	L-1	L	L-4	L-3	L-2	L-1	L
60 RPM	160	166	172	178	182	106.1	120.3	136.3	163.0	175.7
	3.9	4.0	4.1	4.7	4.0	3.9	3.3	6.1	4.9	7.0
80 RPM	164	170	175	180	185	113.6	129.6	148.6	170.2	188.1
	3.3	3.2	3.3	3.7	2.9	3.4	3.5	5.3	5.2	10.5
100 RPM	163	169	174	179	183	115.6	135.4	152.8	173.9	191.5
	4.4	3.7	3.5	3.7	4.4	4.2	4.2	4.8	4.9	7.3
120 RPM	162	168	174	179	182	114.1	137.7	161.3	181.2	187.6
	4.7	4.3	3.9	4.4	4.0	18.7	8.7	5.9	3.9	4.5
BIKE	162	168	174	179	183	112.2	130.8	149.8	172.1	185.7
	1.9	1.8	1.7	1.8	1.8	3.9	2.9	3.3	2.6	3.8
6.0 MPH	163	176	179	184	187	118.8	134.3	151.4	167.3	181.9
	4.3	4.8	4.5	4.1	3.7	3.4	4.4	5.7	6.4	5.0
6.5 MPH	169	175	180	184	186	115.8	136.3	153.2	169.4	178.8
	5.3	5.0	4.9	4.0	3.8	5.3	5.2	7.6	7.4	4.1
7.0 MPH	162	169	176	181	186	102.1	128.3	141.9	160.1	176.3
	5.7	4.9	4.5	4.3	3.9	8.4	7.6	4.0	3.7	5.0
7.5 MPH	163	170	178	183	186	105.9	126.5	145.3	165.3	174.7
	5.7	4.0	3.9	3.7	3.6	8.7	5.0	8.8	5.5	5.0
TREAD-MILL	166	172	179	183	186	110.7	131.4	147.9	165.6	177.9
	2.5	2.2	2.0	1.9	1.7	2.3	2.3	2.4	2.8	2.8
ALL	164	170	176	181	185	111.4	131.1	148.9	168.8	181.8
	1.6	1.5	1.4	1.3	1.3	2.6	2.0	2.3	2.0	2.3

TABLE 9

EXHAUSTIVE EXERCISE: Mean and standard error of respiratory gas exchange for five male subjects in either the last or penultimate minute of exhaustive exercise at various pedal frequencies and running speeds. Values are those from the minute showing the greater oxygen uptake. Ventilation VENT (BTPS, L/MIN), Oxygen Uptake VO (STPD, L/MIN) and MLKG (STPD, ML/KG/MIN), Carbon Dioxide Expired (STPD, L/MIN), Respiratory Gas Exchange RER, Ventilatory Equivalent VE, Percentage Oxygen Extraction OE.

TEST	VENT	VO	MLKG	VCO	RER	VE	OE
60 RPM	173.3	4.543	57.60	5.226	1.15	38.24	3.30
	7.1	0.112	3.94	0.080	0.03	1.79	0.15
80 RPM	177.0	4.703	59.87	5.390	1.15	37.66	3.35
	9.3	0.104	3.82	0.135	0.02	1.91	0.17
100 RPM	190.7	4.619	58.64	5.337	1.16	41.33	3.06
	7.8	0.142	4.00	0.176	0.02	1.52	0.11
120 RPM	187.2	4.635	58.70	5.351	1.16	40.57	3.12
	4.3	0.128	4.07	0.091	0.02	1.88	0.14
BIKE	182.0	4.625	58.70	5.326	1.15	39.45	3.21
	3.8	0.058	1.83	0.060	0.01	0.89	0.07
6.0 MPH	182.9	5.041	63.67	6.049	1.20	36.27	3.46
	5.3	0.100	3.27	0.058	0.02	0.52	0.05
6.5 MPH	180.0	5.004	63.34	5.994	1.20	36.03	3.49
	3.7	0.096	4.03	0.116	0.01	1.06	0.11
7.0 MPH	176.3	5.058	64.35	5.737	1.14	34.95	3.59
	5.0	0.133	4.11	0.138	0.01	1.25	0.13
7.5 MPH	172.7	4.893	61.74	5.627	1.15	35.37	3.57
	3.9	0.131	3.42	0.103	0.04	1.06	0.10
TREAD-MILL	178.0	4.999	63.28	5.852	1.17	35.65	3.53
	2.2	0.055	1.72	0.064	0.01	0.48	0.05
ALL	180.0	4.812	60.99	5.589	1.16	37.55	3.37
	2.2	0.050	1.29	0.060	0.01	0.59	0.05

TABLE 10

Two way analysis of variance of parameters listed produced significant (probability less than value shown) F-ratios between testing modes (EQUIPMENT) and among test on eith the BICYCLE or TREADMILL. NS — not significant, NA — not applicable.

	EQUIPMENT	BICYCLE	TREADMILL
WARM-UP			
Oxygen uptake	.05	NS	NS
(L/MIN)	.05	NS	NS
(ML/KG/MIN)	.05	NS	NS
TEST CONDITIONS			
Barometric pressure	NS	.1	NS
EXHAUSTIVE EXERCISE			
Time to exhaustion	NS	.0005	.0005
Work rate	NA	.0005	.0005
Heart rate	.0005	NS	NS
Oxygen uptake (L/MIN)	.005	NS	NS
(ML/KG/MIN)	.005	NS	NS
Carbon dioxide production	.0005	NS	.005
Ventilatory equivalent	.01	.1	NS
RECOVERY			
Heart rate in fifth min.	.05	NS	NS

A significant difference among the treadmill tests was shown in the carbon dioxide production during the last minute of exhaustive exercise ($p < 0.005$).

The differences in the time to exhaustion (Tables 5 and 10) in tests on both bicycle and treadmill produced highly significant F-ratios ($p < 0.0005$). Since the work rate on the bicycle and the grade on the treadmill were time dependent, these parameters in the final minute of exhaustive testing also showed highly significant differences between tests ($p < 0.0005$).

ii. Paired t-tests

Paired t-tests compared the following parameters: relative oxygen uptake (explained below), carbon dioxide production, expired ventilation, and time to exhaustion and the results are shown in Table 12.

Oxygen uptake for each test was expressed as a percentage of the maximum value obtained either on the bicycle or the treadmill for each subject (Table 11). Paired t-tests on these values show significant differences ($p < 0.05$) between 60 and 80 rpm and between 80 and 120 rpm rates of pedalling on the bicycle ergometer. There were no significant differences

TABLE 11a

Relative value of oxygen uptake at exhaustion as a percent of the highest value of oxygen uptake appropriate to each test series (bicycle or treadmill) for five male subjects.

	BICYCLE (RPM)				TREADMILL (MPH)			
	60	80	100	120	6.0	6.5	7.0	7.5
VP	96.1	100.0	94.7	97.6	100.0	93.8	96.2	95.5
MC	99.5	100.0	96.5	96.7	98.7	100.0	95.9	96.3
BN	92.5	99.9	100.0	98.8	100.0	94.0	97.6	91.9
BC	90.0	95.7	100.0	95.0	93.9	94.7	99.8	100.0
JH	100.0	99.6	94.8	99.5	93.7	100.0	97.9	88.1
MEAN	95.62	99.04	97.20	97.52	97.24	96.53	97.46	94.35
SE	1.95	0.84	1.19	0.79	1.44	1.43	0.69	2.02

TABLE 11b

Relative value of oxygen uptake at exhaustion on the bicycle ergometer as a percent of the highest value of oxygen uptake obtained during the treadmill test series for five male subjects.

	BICYCLE (RPM)			
	60	80	100	120
VP	86.9	96.2	85.6	88.3
MC	90.2	90.7	87.5	87.7
BN	84.2	90.5	90.6	89.6
BC	83.6	88.8	92.8	88.2
JH	93.3	92.9	88.5	92.9
MEAN	87.63	91.82	89.00	89.31
SE	1.85	1.28	1.25	0.94

TABLE 12

PROBABLILITY (LESS THAN VALUES SHOWN) of differences in relative oxygen uptake, carbon dioxide production, expired ventilation, time to exhaustion and ventilatory equivalent between exhaustive tests at various pedalling frequencies on the bicycle and at various running speeds on the treadmill. Tests are arranged in ascending order of magnitude (left to right) of the corresponding parameter.

BICYCLE (rpm)						TREADMILL (mph)				
	60	100	120	80			7.5	6.5	6.0	7.0
60	X			.05	RELATIVE	7.5	X			
100		X			OXYGEN	6.5		X		
120			X	.05	UPTAKE	6.0			X	
80				X		7.0				X

	60	100	120	80			7.5	7.0	6.5	6.0
60	X				CARBON	7.5	X	.025	.025	.005
100		X			DIOXIDE	7.0		X	.005	.05
120			X		PRODUCTION	6.5			X	
80				X		6.0				X

	60	120	80	100			7.5	7.0	6.5	6.0
60	X		.05	.05	EXPIRED	6.0	X			
120		X			VENTILATION	6.5		X		
80			X			7.0			X	
100				X		7.5				X

	120	100	80	60			7.5	7.0	6.5	6.0
120	X	.005	.01	.005	TIME	7.5	X	.025	.005	.005
100		X		.05	TO	7.0		X	.005	.005
80			X		EXHAUSTION	6.5			X	.01
60				X		6.0				X

	80	60	120	100			7.0	7.5	6.5	6.0
80	X			.025	VENTILATORY	7.0	X			
60		X		.01	EQUIVALENT	7.5		X		
120			X			6.5			X	
100				X		6.0				X

in relative oxygen uptake in exhaustive treadmill tests at various running speeds.

Paired t-tests comparing carbon dioxide production during different treadmill tests at various speeds and grades showed that carbon dioxide production at 7.5 mph was significantly lower than at 7.0, 6.5 ($p < 0.025$) and 6.0 mph ($p < 0.005$); at 7.0 mph it was significantly lower than at 6.5 mph ($p < 0.005$); at 7.0 mph it was significantly lower than at 6.0 mph ($p < 0.05$).

Paired t-tests showed no significant differences in the carbon dioxide production for the various pedalling frequencies during bicycle ergometry.

Paired t-tests of expired ventilation at exhaustion at different pedalling frequencies showed significant differences between 60 rpm and 80 rpm ($p < 0.05$) and between 60 rpm and 120 rpm ($p < 0.05$) pedalling frequencies respectively during bicycle ergometry.

Endurance at a pedalling frequency of 120 rpm was shown to be shorter in duration than at 60 and 100 rpm ($p < 0.005$), or at 80 rpm ($p < 0.01$). At 100 rpm exercise endurance was of significantly shorter duration than that at 60 rpm tests ($p < 0.05$).

Time to exhaustion on all tests on the treadmill were significantly different from one another. Endurance at 6.0 mph was significantly longer than at 6.5 mph ($p < 0.01$), 7.0 mph ($p < 0.005$) or 7.5 mph ($p < 0.005$); endurance at 6.5 mph was significantly longer than that at 7.0 mph ($p < 0.005$) and 7.5 mph ($p < 0.005$); endurance at 7.0 mph was significantly longer than that at 7.5 mph ($p < 0.025$).

Recovery and Blood Chemistry

The heart rate after five minutes of recovery (Table 13) showed a difference ($p < .05$) between the values obtained following exhaustive exercise on the bike and treadmill, 104 (SE 1.3) and 98 (SE 2.0) beats per minute respectively.

There were no significant differences between bicycle or treadmill or among tests using the same equipment for lactate or hemoglobin concentration, and hematocrit following exhaustive exercise. (Table 14)

TABLE 13

RECOVERY: Mean and standard error for heart rate (bpm) and ventilation (BTPS, L/MIN) for five male subjects for five minutes of recovery following exhaustive exercise at various pedal frequencies and running speeds shown in the left-hand column.

TEST	HEART RATE					VENTILATION				
	1	2	3	4	5	1	2	3	4	5
60 RPM	152	126	112	106	102	145.9	98.2	71.3	58.8	51.6
	4.7	3.9	5.0	4.0	1.5	4.6	5.8	8.3	6.5	6.3
80 RPM	156	129	116	107	105	153.3	106.5	76.4	62.4	56.6
	4.6	3.9	2.4	2.6	2.4	5.3	6.2	5.4	2.3	4.5
100 RPM	151	127	112	109	105	148.0	102.7	73.1	63.7	54.6
	8.0	4.4	4.0	4.9	3.0	7.3	5.6	7.3	4.7	4.7
120 RPM	148	124	114	109	104	154.1	107.5	81.3	67.1	55.1
	5.0	6.0	4.0	3.3	3.7	2.1	2.7	6.0	5.8	4.4
BIKE	152	126	114	108	104	150.3	103.7	75.5	63.0	54.5
	2.7	2.2	1.9	1.6	1.3	2.5	2.6	3.3	2.4	2.4
6.0 MPH	149	120	112	102	99	150.3	113.5	91.2	75.5	60.2
	7.6	7.4	4.6	5.2	4.1	3.1	3.4	4.2	6.3	4.3
6.5 MPH	150	123	107	103	98	148.2	114.1	85.0	69.5	53.9
	5.8	5.1	5.5	5.4	4.2	4.8	5.3	7.7	5.4	7.5
7.0 MPH	153	125	104	99	95	145.4	114.6	88.8	68.2	57.7
	6.4	6.1	6.7	4.8	3.7	3.1	4.7	4.1	5.0	5.7
7.5 MPH	145	117	105	102	98	148.6	104.5	78.8	67.8	55.1
	6.7	6.6	5.8	5.1	5.2	8.1	4.4	5.2	5.5	4.0
TREAD-	149	121	107	101	98	148.0	111.7	86.0	70.2	56.7
MILL	3.1	3.0	2.7	2.4	2.0	2.5	2.3	2.7	2.7	2.6
ALL	151	124	110	105	101	149.2	107.7	80.7	66.6	55.6
	2.1	1.9	1.7	1.5	1.3	1.8	1.8	2.3	1.9	1.7

TABLE 14

BLOOD CHEMISTRY: Mean and standard error for lactate (LA, mg/100 ml), hemoglobin (HB, g/100 ml) and hematocrit (HE) analysis of blood samples taken immediately following warm-up (WU) and during recovery following exhaustive exercise by five male subjects in the test indicated in the left-hand column where LAMAX is the larger of the two values obtained from the post-exercise blood samples.

TEST	LAWU	LA-R*	HBWU	HB-R	HEWU	HE-R
60 RPM	37.8	121.5	14.7	15.4	49.9	51.1
	9.9	10.6	0.6	0.6	1.3	1.0
80 RPM	45.6	141.6	15.0	15.6	50.1	51.3
	7.1	5.0	0.5	0.6	0.8	1.3
100 RPM	42.8	135.6	15.0	15.6	49.0	51.3
	6.9	5.6	0.5	0.5	0.8	1.2
120 RPM	46.4	134.7	15.1	15.6	49.6	51.6
	8.9	6.8	0.8	0.7	1.0	1.0
BIKE	43.1	133.3	14.9	15.6	49.7	51.4
	3.9	3.8	0.3	0.3	0.5	0.5
6.0 MPH	43.3	137.2	14.7	15.1	40.3	52.3
	7.6	9.8	0.4	0.3	10.1	0.8
6.5 MPH	45.9	139.8	15.4	15.9	50.0	52.0
	9.0	12.0	0.4	0.5	0.9	1.0
7.0 MPH	44.2	137.8	14.4	14.8	49.1	50.7
	7.9	7.0	0.5	0.5	1.0	0.7
7.5 MPH	47.0	134.0	15.0	15.3	50.1	51.1
	7.4	12.5	0.5	0.5	1.2	1.2
TREAD-MILL	45.1	137.2	14.9	15.3	47.4	51.5
	3.7	4.9	0.2	0.2	2.5	0.5
ALL	44.1	135.3	14.9	15.4	48.5	51.4
	2.7	3.0	0.2	0.2	1.3	0.3

* LA-R mean and standard error of the larger value obtained from blood samples taken at five and eight minutes recovery.

CHAPTER IV

DISCUSSION

Warm-up Protocol

A warm-up exercise period prior to strenuous exercise has proved to be beneficial in improving performance. (Simonsen et al., 1936; Asmussen and Boje, 1945). These authors showed that for each degree of temperature increase, there is approximately a 13 percent increase in the rate of cell metabolism.

Högberg and Ljunggren (1947) suggested a minimum of 15 minutes of warm-up (3.0 to 3.4 liter oxygen uptake/min) prior to an athletic event. They have also suggested that the rest period between warm-up and the start of a race should be ideally only a few minutes and definitely no more than fifteen.

In the present experiment, the average warm-up oxygen uptake (3.254 liters oxygen/min) is in accord with the above requirements. The rest period before exhaustive exercise after standard exercise in the present study was between 15 and 20 minutes. This should not have affected the final results as the first 3 to 4 minutes of each exhaustive test could also be considered as an additional warm-up immediately period prior to strenuous exercise.

Table 15 shows an estimate of the intensity of the warm-up exercise in relation to the mean oxygen uptake at exhaustion for each subject. The average value of 67.7% of maximum is higher than a required estimate of 50% used by Kamon and Pandolf (1972) in comparing laddermill climbing, uphill running and cycling but compares favorably with the 50 - 70% value used by Hermansen and Saltin (1969) for maximal treadmill and bicycle exercise.

TABLE 15

WARM-UP OXYGEN UPTAKE: Mean warm-up oxygen uptake (WU) as a percentage of the mean exhaustive oxygen uptake (EX) for all tests for each subject.

SUBJ	WU L/MIN	EX L/MIN	% WU/EX
VP	3.296	4.759	69.3
MC	3.293	4.458	73.9
BN	3.324	4.903	67.8
BC	3.396	4.965	68.4
JH	2.962	4.974	59.5
MEAN	3.254	4.812	67.7

Warm-up work rates were predicted to ellicit heart rates of 150 bpm but the mean heart rate for warm-up was only 145 bpm. (Table 6) The duration of continuous exercise (> 10 min) during the initial PWC170 tests may have caused an attendant increase in body temperature and subsequent elevation of heart rate accounting for this error. Mostardi et al. (1974) found that the heart rate for a standard rate of stepping up and down on a bench was always higher after prolonged exercise. A rectal temperature increase of 1 °C caused an increase in heart rate of 17 bpm at 15 steps/min and 7 bpm at 25 steps/min.

Warm-up exercise (cycling at 60 rpm) prior to all exhaustive tests (bicycle or treadmill) was essentially the same throughout this study. In other tests of maxiamal aerobic capacity, warm-up exercise was of the same type as was used in the subsequent maximal exercise test (Kamon and Pandolf, 1972; Hermansen and Saltin, 1972). There are, to this author's knowledge, no definitive papers on the effect of warm-up on the results of an exhaustive tests.

Sensitivity of Statistical Analysis

Garrett (1965) has pointed out that a two-way analysis of variance and F-ratio is a comprehensive test of the significance of difference between means.

A significant F-ratio does not distinguish which means differ significantly but indicates that at least one is reliably different from the others. In the present study, only five subjects were tested and the standard error of the means was large (SE's vary inversely as the square root of the sample size). A larger sample size may have produced further significant F-ratios, but this is only speculation.

A significant F-ratio was obtained for the difference between the mean warm-up oxygen uptakes prior to bicycle (3.273 l/min) and treadmill (3.235 l/min) testing. The experimental error was extremely small and thus produced a spuriously significant F-ratio. The absolute difference between the means was not great and, for the purpose of a standardized warm-up, was quite acceptable.

Exhaustive Exercise

i. Bicycle vs. Treadmill

This study is probably one of the most exhaustive and precise evaluations of VO2max at various pedalling frequencies on the bicycle ergometer and running speeds on the treadmill. The results substantiate earlier reports that exhaustive tests using the treadmill ellicit greater oxygen uptakes than the bicycle ergometer. Mean oxygen uptake for all the bicycle ergometer tests (4.625 l/min) was 7.48 % less than for the treadmill tests (4.999 l/min). Other investigators have reported differences of 13-15% (Ikai _et al._, 1970), 10.2 - 11.2% (McArdle _et al._, 1973), 8% (Glassford _et al._, 1965), 7% (Hermansen and Saltin, 1969), and 6% (Hermansen _et al._, 1970).

Oxygen uptake at exhaustion during bicycle ergometry, expressed as a percentage of the largest value obtained for each subject during treadmill running (Table 11), ranged from 16.4% to 3.8% (Mean 10.5%) less than the largest treadmill value for each subject. The discrepancy in relative oxygen uptake differences between the two pieces of equipment complicated and contributed to by the relative effectiveness of the various tests to ellicit an individual's maximum aerobic power and/or the individual's preference for a particular test. These factors may explain the variance in VO2max and are largely responsible for the uncertainty surrounding any protocol of maximal testing. These points will be discussed later in greater detail.

The present study showed heart rate at exhaustion on the treadmill (186 beats/min) to be significantly greater than on the bicycle ergometer (183 beats/min) ($p < 0.005$) and substantiates the results of Miyamura and Honda (1972) and

Hermansen *et al.* (1970). The former study recorded mean heart rates of 192 and 179 beats/min for treadmill and bicycle respectively, while the latter was similar to the present study with values of 187 and 185 beats/min respectively. This discrepancy may be explained, in part, by the fact that the average age of the subjects in the studies were quite different: 24.8 yrs (present study), 19.9 yrs (Miyamura and Honda) and 24.2 yrs (Hermansen *et al.*)

In some studies (Glassford *et al.*, 1965; Wyndham *et al.*, 1966; Hermansen *et al.*, 1970; Miyamura and Honda, 1972) where a significantly lower VO2max has been observed during bicycle compared with treadmill exercise, the suggestion that the early development of local muscular fatigue during maximal bicycling limits the work performance, has been made. This fatigue occurs before the central circulation is maximally engaged and results also in a lower maximal heart rate in ergometer exercise.

Ventilation at exhaustion was generally higher in cycling than in running. However, the difference was not significant and compares favorably with the results of Kamon and Pandolf (1972) even though their values (B=126.0, TM=120.9 l/min) were much lower than in the present study.

Åstrand and Rodahl (1970) observed that the ventilatory equivalent (liters ventilation / liters oxygen uptake) is in the range of 30 to 35 during maximal work. In the present study the means for bicycle and treadmill were 39.45 and 35.65, respectively. The higher value for bicycle exercise may be partially due to the pedalling frequencies used in the exhaustive tests which produced significantly greater ventilatory volumes in the 80 and 100 rpm tests than in the 60 rpm test.

Kamon and Pandolf (1972) also obtained a significantly greater mean ventilatory equivalent during bicycle exercise (35.0) compared to treadmill exercise (29.9). The lesser values are the result of much lower expiratory ventilation during maximum exertion.

Kamon and Pandolf (1972) and the present study showed significant ventilatory equivalent differences between bicycle and treadmill exhaustive exercise, but these are merely reflections of the significant differences in oxygen uptake at exhaustion, as in both studies, there were no differences in maximal ventilation.

ii. Bicycle Ergometery

Bicycle ergometry has been used extensively in exercise testing for many years. Although a statement from the International Congress of Sports Medicine (1966) implied that further concerted actions to the standardization of ergometry were planned, no comprehensive study of the influence of pedalling frequency on VO2max has been reported.

The present study has shown a pedalling frequency of 80 rpm to produce significantly greater VO2max than frequencies of either 60 or 120 rpm. There was no difference between the VO2max values obtained at 80 and 100 rpm and thus either of these pedalling frequencies would seem to be most suitable for maximal bicycle testing.

Hermansen and Saltin (1969) studying the effects of pedalling frequencies of 50, 60 and 70 rpm found that VO2max was greatest at 60 rpm. However, their procedure (Åstrand and Saltin, 1961) consisted of a 10 minute warm-up at approximately 50% OF maximum aerobic capacity followed immediately by a constant work rate predicted to cause exhaustion within ten minutes. Their choice of 60 rpm over 70 rpm is in disagreement with the present study and may be a result of the difference in testing format or their ability to predict the most suitable work rate to produce exhaustion.

Hermansen and Saltin (1969) stated that 80 rpm is too high a frequency to obtain the highest possible oxygen uptake on the bicycle. However, Shephard et al. (1968) and Gleser and Vogel (1973) allowed their subjects to choose pedalling frequencies in the ranges of 60 to 90 rpm and 40 to 80 rpm respectively. Faulkner (1971) chose 80 rpm to approximate the 87 strides /min (174 steps/min) with each leg while running at 8 mph. This choice seems to be in agreement with the 190-200 steps/min (level running) and 160 steps/min (uphill running, 5.25% grade) estimated by Hermansen and Saltin (1969).

Hoes et al (1968) indicated that a professional cyclist much preferred pedalling at 80 rpm. Pugh (1974) allowed his subjects (1 professional and 5 amateur cyclists) complete freedom of choice in pedalling frequency during work rates up to the maximum that the subjects could maintain for four to five minutes. The general choice (interpretation of a graph) appears to be between 70 and 95 rpm.

Banister and Jackson (1967) suggested that the low pedalling rates (30-60 rpm) indicated by the International Congress of Sports Medicine (1966) necessitate larger frictional resistance to the ergometer wheel for higher power outputs. Thus, leg strength, primarily of the quadriceps, may become the limiting factor rather than the cardiovascular -

pulmonary ventilation system. This is particularly true when one considers that in one cycle the peak loads are about twice the load-setting on the ergometer (Hoes et al., 1968).

Banister and Jackson (1967) also suggested that maximum ventilation is an essential for obtaining values of maximal aerobic power. In the present experiment, ventilatory rates for the 80 and 100 rpm bicycling tests were significantly greater than obtained during the 60 rpm exhaustive test.

The statement that pedalling frequency may influence pulmonary ventilation (Hermansen and Saltin, 1969) was confirmed by Asmussen (1973). He discovered that increasing pedalling frequency (36, 60 and 90 rpm) at zero work load caused concomitant increases in ventilation due to increases in both the respiratory frequency and the tidal volume. The corresponding increase in pedalling frequency and ventilation was also shown at the submaximal work rate of 1080 kgm/min. Asmussen suggested that the frequency of leg movement and mechanical tension in the exercising muscles caused a stimulus to be "fed back to the central or peripheral respiratory motor centers in such a way that the respiratory stimuli produce larger ventilation."

iii. Treadmill Running

Shepherd *et al.* (1968) and Wyndham *et al.* (1966) recommended uphill treadmill running as the most accurate and reliable method of assessing VO2max. Comparisons of continuous and discontinuous (rest period between test levels) treadmill testing showed no significant differences in the resulting maximum oxygen uptakes.

The present study examined continuous maximal treadmill running at 6.0, 6.5, 7.0 and 7.5 mph with grade increases of 2.5%/min. The resulting maximum oxygen uptakes for each speed were not significantly different. Three of the five subjects obtained their lowest and one (BC) his highest oxygen uptake in the 7.5 mph test. The resulting mean value for the 7.5 mph test was approximately 2.8% lower than each of the other treadmill tests. The other highest individual values were obtained in the 6.0 (VP, BN) and 6.5 (MC, JH) mph tests. Subject BC, a trained sprinter (440 yd. in 54 sec.), increased his VO2max with increasing test speeds and was the only one to exhibit any consistant trend.

Individual preference for a particular running speed on an incline appears to be a significant factor in exhaustive treadmill testing. The speed of choice may be dependant upon one or a combination of factors, i.e. age, weight, leg strength, type of training or track experience. Subjects VP, MC and BN were subjectively viewed to have superior leg strength and thus were better equipped for the slower, more labourious uphill toil of slower speeds at steeper inclines. Subject JH, the best runner of the group (4:13 mile and 15:05 5000 meters), obtained his highest oxygen uptakes at 6.5 and 7.0 mph.

No previous study seems to have examined exhaustive testing at various running speeds and identical increases in gradient. This scheme of testing produces a more rapid increase in work rate (the grade dictates the angle of rise, the combination of speed and grade dictates the rate of rise) and also a significantly earlier termination at the faster than at the slower speeds. Subjects, prior to exhaustion, must compete against steeper gradients at slower speeds which may, in part, explain higher respiratory exchange ratios and significantly greater carbon dioxide volumes at slower speeds. An increased respiratory exchange ratio has been reported to be indicative of an increased level of anaerobic metabolism (Issekutz et al., 1962; Wasserman and McIlroy, 1964).

Use of the treadmill as an ergometer has been severely limited by inability of ivestigators to evaluate work rates at given combinations of speed and grade. Margaria _et al_. (1963) found the energy cost of running to be a linear function of speed; i.e., the net cost of level running is 1 kcal/kg km. Taylor _et al_. (1955), using discontinuous testing at 7 mph, found a 2.5% increase in grade elicited an increase in oxygen uptake of 299.3 ml/min. Definitive investigation of the energy cost of treadmill running at specific combinations of speed and grade would prove to be a definite asset to the field of exercise testing.

Recovery

The difference between five minute recovery heart rates following exhaustive bicycle ergometry and treadmill running is most likely due to differences in the type and amount of activity during recovery. The subjects remained seated following bicycle tests and either continued to pedal slowly with little or no resistance or sat motionless with their feet resting on foot rests. After the majority of treadmill tests, subjects walked slowly on the level for the duration of the recovery period. The greater muscular involvement following treadmill exercise may have aided venous return and thus increased the rate of heart rate recovery compared with a more leisurely protocol following bicycle ergometry.

Blood lactate concentration (> 80 mg/100ml) following exhaustive exercise has historically been one of the prime indicators that maximum aerobic capacity has been reached (Åstrand, 1952). The time at which to draw blood samples has been questioned and in the present study, samples were drawn at five and eight minutes post exercise. Lactate concentration five minutes post exercise was significantly greater that at eight minutes. This disputes the study by Margaria _et al_. (1963) which showed increased blood lactate concentrations up to eight minutes post exercise. In the present study, approximately 95% of the post exercise blood samples showed the five minute sample to produce the greater lactate concentration. Differences in cardiovascular efficiency of the subjects in the present study relative to Margaria's may explain this contradiction. Margaria used two non-athletes and one athlete compared with the five well trained athletes in the present study.

Test Preference

Shephard _et al_. (1968) reported that 11 of their subjects preferred treadmill testing, 9 preferred bicycle and the remaining 5 preferred step-tests. Two of the five subjects in the present experiment preferred bicycle riding at 60 or 80 rpm over treadmill tests. The remaining three subjects preferred the 6.0 mph (JH) and the 7.0 mph (BN, BC) treadmill tests. The subjects were agreed in their general dislike of 120 rpm bicycle and 7.5 mph treadmill tests.

McArdle and Magel (1970) observed that 2 of 23 subjects attained higher maximum oxygen uptakes on bicycle (60 rpm) compared to treadmill (walking 3.4 mph) tests. These two subjects, however, were reported to have been involved in bicycling as a common form of outdoor recreation. In the present experiment, two subjects showed higher maximum oxygen uptakes in bicycle ergometry (80 rpm) than in the 7.5 mph (JH, VP), 6.5 mph (VP) and 6.0 mph (VP) treadmill tests. The preceding facts may be misleading as subjective examination of data indicates that the VO2max for VP (80 rpm) was much higher than at other pedalling frequencies on the bicycle and for JH (7.5 mph) was much lower compared to other treadmill speeds.

Edwards *et al.* (1972) suggested that rating of perceived exertion (RPE) may correlate well with the intensity of afferent nervous information arising in the muscles, tendons and joints of the legs during work. RPE whould then be greater the more intense was the activity of the legs, i.e. frequency of movements, tension in muscles or tendons or forces exerted on joints.

Pandolf and Noble (1973) investigated RPE as affected by equivalent submaximal power outputs at pedalling frequencies of 40, 60 and 80 rpm. The RPE was found to be generally negatively related to pedalling speed although the difference was not statistically significant between 60 and 80 rpm.

In the present study, the preferred pedal frequencies for maximal testing were 80 rpm (VP, MC, BC), 100 rpm (BN) and 60 rpm (JH). These preferences appear to agree with the results of Pandolf and Noble (1973), assuming that the subjects' preferred test was also that of least perceived exertion. This also suggests the possibility that exhaustion at high pedalling frequencies may incorporate a different weighting of the components; exerted force, tension in muscles and tendons and frequency of movement, in reference to perceived exertion.

Hill (1966) demonstrated the existence of a hyperbolic force-velocity relationship in muscular contraction. The product of force and velocity is power output and the latter has been shown to be maximal when the velocity of contraction is approximately one third of its maximum. There are, in fact, many force-velocity relationships, each corresponding to a different length of the muscle being observed. It may be stated that in cycling, there is an average force-velocity relationship throughout a pedalling cycle and it can be expressed in terms of the average force applied during a pedalling cycle in relation to the pedalling frequency. In this case power output is the product of average force and pedalling frequency. Therefore it may be assumed that there is a pedalling frequency at which a given individual is capable of acheiving his maximum power output. Future studies might attempt to discern whether or not this pedalling frequency is that which will elicit the individual's VO2max. Such a finding would suggest that tests of VO2max be standardized according to this measure of maximum power output rather than according to a fixed pedalling frequency for all individuals.

CHAPTER V

CONCLUSION

Maximal testing by incline running on the treadmill remains the most effective mode for testing aerobic capacity. Speed of running appears to have little or no effect on maximal oxygen uptake.

Maximal oxygen uptake assesssment by bicycle ergometery gives significantly lower values than inclined treadmill running. Previous suggestions in the literature regarding bicycle ergometry that there exists an optimal relationship between pedalling frequency, force development, and power output and the results of the present study provide a strong argument for the use of pedalling frequencies greater than 80 rpm in bicycle testing for maximum cardio-respiratory function.

Shephard et al. (1968) stated that maximum oxygen uptake by direct measurement should be accepted as the absolute criterion against which other procedures are to be judged. Before accepting maximum oxygen uptake as an international standard of reference, however, it is important to ensure also that the measurement is practical and yields reproducible values.

The present study has surveyed a greater range of pedalling frequencies and running speeds than has been attempted previously. A better understanding of these factors, should aid deliberations in development of an international standard of reference.

BIBLIOGRAPHY

Andersen, K. L., R. J. Shephard, H. Denolin, E. Varnauskas and R. Masironi. Fundamentals of Exercise Testing. World Health Organization, Geneva, 1971.

Asmussen, E. and O. Boje. Body temperature and capacity for work. Acta Physiol. Scand. 10:1, 1945. Cited by P. O. Astrand and K. Rodahl. Textbook of Work Physiology. McGraw-Hill Book Co., Toronto, 1970.

Asmussen, E. Ventilation at transition from rest to exercise Acta Physiol. Scand. 89:68–78, 1973.

Asmussen, E. and I. Hemmingsen. Determination of maximum working capacity at different ages in work with legs or with the arms. Scand. J. Clin. Lab. Invest. 10: 67-71, 1958.

Åstrand, I. Aerobic work capacity in men and women with special reference to age. Acta Physiol Scand. 49(Suppl. 169), 1960.

Åstrand, P. O. Experimental Studies of Physical Working Capacity in Relation to Sex and Age. Munksgaard, Copenhagen, 1952.

Åstrand, P. O. Human physical fitness with special reference to sex and age. Physiol. Rev. 36: 307–335, 1956.

Åstrand, P. O., I. Hallback, R. Hedman, B. Saltin. Blood lactates after prolonged severe exercise. J. Appl. Physiol. 18(3): 619-622, 1963.

Åstrand, P. O. and K. Rodahl. Textbook of Work Physiology. McGraw-Hill Book Co., Toronto, 1970.

Åstrand, P. O. and B. Saltin. Maximal oxygen uptake and heart rate in various types of muscular activity. J. Appl. Physiol. 16(6): 977–981, 1961.

Balke, B. and R. W. Ware. An experimental study of physical fitness of air force personnel. U.S. Armed Forces Med. Journal. 10: 675– 688, 1959.

Bang, O. The lactate content of the blood during and after muscular exercise in man. Scand. Archiv. Physiol., Leipzig. 74 (suppl. 10): 49–82, 1936.

Banister, E. W. and R. C. Jackson. The effect of speed and load changes on oxygen intake for equivalent power outputs during bicycle ergometry. Int. A. angew Physiol. einschl. Arbeitsphysiol. 24: 284-290, 1967.

Bobbert, A. C. Physiological comparison of three types of ergometry. J. Appl. Physiol. 15: 1007-1014, 1960.

Cunningham, D. A., H. J. Montoye, H. L. Metzner and J. B. Keller. Physical activity at work and active leisure as related to occupation. Med. and Sci. in Sports. 1(3): 165-170, 1969.

Davies, C. T. M., W. Tuxworth and J. M. Young. Physiological effects of repeated exercise. Clin. Sci. 39: 247-258, 1970.

Diamant, B., J. Karlsson and B. Saltin. Muscle tissue lactate after maximal exercise in man. Acta Physiol Scand. 72: 383-384, 1968.

di Prampero, P. E. L. Peeters and R. Margaria. Alactic Oxygen debt and lactic acid production after exhausting exercise in man. J. Appl. Physiol. 34(5):628-632, 1973.

Dixon, W. J. (editor). BMD Biomedical Computer Programs. University of California Press, Berkeley, Los Angeles, 1973.

Edwards, R. H. T., L. G. Ekelund, R. C. Harris, C. M. Hesser, E. Hultman, A. Melcher and O. Wigertz. Cardiorespiratory and metabolic costs of continuous and intermittent exercise in man. J. Physiol. 234: 481-497, 1973.

Edwards, R. H. T., A. Melcher, C. M. Hesser, O. Wigertz and L. -G. Ekelund. Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. Eur. J. Clin. Invest. 2: 108-114, 1972.

Faulkner, J. A., D. E. Roberts, R. L. Elk and J. Conway. Cardiovascular responses to submaximum effort cycling and running. J. Appl. Physiol. 30: 457-461, 1971.

Garrett, H. E. Statistics in Psychology and Education. David McKay Co., Inc., New York, 1965.

Glassford, R. G., G. H. Y. Baycroft, A. W. Sedgwick and R. B.J. MacNab. Comparison of maximal oxygen uptake values determined by predicted and actual methods. J. Appl. Physiol. 20(3): 509-513, 1965.

Gleser, M. A. and J. A. Vogel. Endurance capacity for prolonged exercise on the bicycle ergometer. J. Appl. Physiol. 34(4): 438-442, 1973.

Hanson, J. S. Maximal exercise performance in members of the U.S. Nordic Ski Team. J. Appl. Physiol. 35(5): 592-595, 1973.

Hermansen, L. and K. L. Anderson. Aerobic work capacity in Young Norwegian men and women. J. Appl. Physiol. 20(3): 425-431, 1965.

Hermansen, L., B. Ekblom and B. Saltin. Cardiac output during submaximal and maximal treadmill and bicycle exercise. J. Appl. Physiol. 29(1): 82-86, 1970.

Hermansen, L. and B. Saltin. Oxygen uptake during maximal treadmill and bicycle exercise. J. Appl. Physiol. 26: 31-37, 1969.

Hermansen, L. and I. Stensvold. Production and removal of lactate during exercise in man. Acta Physiol. Scand. 86: 191-201, 1972.

Hettinger, T., N. C. Birkhead, J. M. Horvath, B. Issekutz and K. Rodahl. Assessment on physical workcapacity. J. Appl. Physiol. 16: 153-156, 1961.

Hill, A. V. A further challenge to biochemists. Biochem. Z. 345: 1, 1966. Cited by J. R. Bendall. Muscles, Molecules and Movement. An essay in the contraction of muscles. Heinemann, London, 1970.

Hirche, H., H. D. Langohr and U. Wacher. Lactic acid permeation from skeletal muscle. Pflügers Archiv. 319(3/4): R109, 1970. cited by J. Karlsson. Lactate and phosphagen concentrations in working muscle of man. Acta Physiol. Scand. Suppl. 358: 1971.

Hoes, M. J. A. J. M., R. A. Binkhorst, A. E. M. C. Smeekes-Kuvi, and A. C. A. Vissers. Measurement of forces exerted on pedal and crank during work on a bicycle ergometer at different loads. Int. Z. angew. Physiol. einschl. Arbeitsphysiol. 26: 33-42, 1968.

Högberg, P. and O. Ljunggren. Uppvärmningens inverkan på löpprestationerna. Svensk Idrott. 40: 1947. Cited by P. O. Åstrand and K. Rodahl. Textbook of Work Physiology. McGraw-Hill Book Co., Toronto, 1970.

Hohorst, H. J. In: Bergmeyer, H. U. Methods of Enzymatic Analysis Academic Press, New York, p. 226, 1965.

Horvath, S. M. and E. D. Michael Jr. Responses of young women to gradually increasing and constant load maximal exercise. Med. and Sci. in Sports. 2(3): 128-131, 1970.

Ikai, M., K. Ishii, M. Miyamura, K. Kusano, O. Bar-Or, J. Kollias and E. R. Buskirk. Aerobic capacity of Ainu and other Japanese on Hokkaido. Med. and Sci. in Sports. 3(1): 6-11, 1971.

Ikai, M., M. Shindo and M. Miyamura. Aerobic work capacity of Japanese people. Res. J. Phys. Educ. 14: 137-142, 1970.

Issekutz, B., N. C. Birkhead, and K. Rodahl. Use of respiratory quotients in assessment of aerobic work capacity. J. Appl. Physiol. 17(1): 47-50, 1962.

Johnson, R. E. Applied physiology. Ann. Rev. Physiol. 8: 535-558, 1946.

Jorfeldt, L. Metabolism of L (+)- lactate in human skeletal muscle during exercise. Acta Physiol. Scand. Suppl. 338, 1970.

Kamon, E. and K. B. Pandolf. Maximal aerobic power during laddermill climbing, uphill running and cycling. J. Appl. Physiol. 32: 467-473, 1972.

Karlsson, J. Lactate and phosphagen concentrations in working muscle of man. Acta Physiol. Scand. Suppl. 358, 1971.

Karlsson, J. and B. Saltin. Lactate, ATP and CP in working muscles during exhaustive exercise in man. J. Appl. Physiol. 29(5): 598-602, 1970.

Kasch, F. W., W. H. Phillips, J. E. L. Carter and J. L. Boyer. Cardiovascular changes in middle-aged men during two years of training. J. Appl. Physiol. 34(1): 53-57, 1973.

Kasch, F. W., W. H. Phillips, W. D. Ross, J. E. L. Carter and J. L. Boyer. A comparison of maximal oxygen uptake by treadmill and step-test procedures. J. Appl. Physiol. 21 (4): 1387-1388, 1966.

Katch, V. L. and F. I. Katch. The relationship between aerobic power and measured work-output on a progressive step increment bicycle ergometer test. Med. and Sci. in Sports. 5(1): 23-28, 1973.

Kirk, Roger E. Experimental Design: Procedures for the behavioral Sciences. Brooks/Cole Publishing Co., Belmont, California, 1968.

Kübler, W., H. J. Bretschneider, W. Voss, H. Gehl, F. Wenthe and J. L. Colas. Über die Milchsäure- und Brenztraubensäure—permeation aus dem hypothermen Myokard. Pflügers Archiv. 287: 203-223, 1966. cited by J. Karlsson. Lactate and phosphagen concentrations in working muscle of man. Acta Physiol. Scand. Suppl. 358: 1971.

Larson, L. A. An international research program for the standardization of physical fitness tests. J. of Sports Med. and Phys. Fitness. 6: 259-263, 1966.

Maksud, M. G. and K.D. Coutts. Comparison of a continuous and discontinuous graded treadmill test for maximal oxygen uptake Med. and Sci. in Sports. 3(2): 63-65, 1971.

Margaria, R., P. Cerretelli, P. E. di Prampero. C. Massari and G. Torelli. Kinetics and mechanism of oxygen debt contraction in man. J. Appl. Physiol. 18: 371-377, 1963.

Margaria, R., P. Cerretelli and F. Mangili. Balance and kinetics of anaerobic energy release during strenuous exercise in man. J. Appl. Physiol. 19: 623-628, 1964.

McArdle, W. D., F. I. Katch and G. S. Pechar. Comparison of continuous and discontinuous treadmill and bicycle tests for maximum VO2. Med. and Sci in Sports. 5(3): 156-160, 1973.

McArdle, W. D. and J. R. Magel. Physical work capacity and maximum oxygen uptake in treadmill and bicycle exercise. Med. and Sci. in Sports. 2: 118-123, 1970.

McDonough, J. R., F. Kusumi and R. A. Bruce. Variations in maximal oxygen intake with physical activity in middle aged men. Circulation. 41: 743-751, 1970.

Métivier, G. and W. A. R. Orban. The Physical Fitness Performance and Work Capacity of Canadian Adults: Ages 18 to 44 years. C.A.H.P.E.R., Ottawa, 1970.

Micael Jr., E. D. and S. M. Horvath. Physical work capacity of college women. J. Appl. Physiol. 20(2): 263-266, 1965.

Mitchell, J. H., B. J. Sproule and C. B. Chapman. The physiological meaning of the maximal oxygen intake tests. J. Clin. Invest. 37: 538-547, 1958.

Miyamura, M. and Y. Honda. Oxygen intake and cardi c output during maximal treadmill and bicycle exercise. J. Appl. Physiol. 32: 185-188, 1972.

Mostardi, R., R. Kubica, A. Veicsteinas and R. Margaria. The effect of increased body temperature due to exercise on the heart rate and on the maximal aerobic power. Europ. J. appl. Physiol. 33(3): 237-245, 1974.

Nagle, F., B. Balke, G. Baptista, J. Alleyia and E. Howley. Compatibility of progressive treadmill, bicycle, and step tests on oxygen uptake responses. Med. and Sci. in Sports. 3:149-154, 1971.

Nei, N., D. H. Bent and C. H. Hull. SPSS Statistical Package for the Socical Sciences. McGraw-Hill Book Co., New York, 1970.

Newton, J. L. The assessment of maximal oxygen uptake. J. Sports Med. and Phys. Fitness. 3: 164-169, 1963.

Pandolf, K. P., and B. J. Noble. The effect of pedalling speed and resistance changes on perceived exertion for equivalent power outputs on the bicycle ergometer. Med. and Sci. in Sports. 5 (2): 132-136, 1973.

Pugh, L. G. C. E. The relation of oxygen intake and speed in competition cycling and comparative observations on the bicycle ergometer. J. Physiol. 241(3): 795-808, 1974.

Rämmal, K. and G. Ström. The rate of lactate utilization in man during work and at rest. Acta Pysiol. Scand. 17: 452-456, 1949.

Robinson, S. Experimental studies in physical fitness in relation to age. Arbeitsphysiologie. 10: 151-323, 1938.

Scholander, P. F. Analyzer for accurate estimation of respirometry gases in one-half cubic centimeter samples. J. Biol. Chem. 167: 235-250, 1947.

Simonsen, E., N. Teslenko and M. Gorkin. Einfluss von Vorübungen auf die Liestung beim 100 m. Lauf. Arbeitsphysiol. 9: 152, 1936. Cited by P. O. Åstrand and K. Rodahl. Textbook of Work Physiology. McGraw-Hill Book Co., Toronto, 1970.

Shephard, R. J.,C. Allen, A. J. S. Benade, C. T. M. Davies, P. E. di Prampero. R. Hedman, J. E. Merriman, K. Myhre and R. Simmons. The maximum oxygen intake: An international reference standard of cardiorespiratory fitness. Bull. W. H. O. 38: 757-764, 1968.

Taguchi, S., P. B. Raven and S. M. Horvath. Comparisons between bicycle ergometry and treadmill walking maximum capacity tests. Jap. J. Physiol. 21: 681-690, 1971.

Taylor, H. L., E. Buskirk and A. Henschel. Maximal oxygen intake as an objective measure of cardio-respiratory performance. J. Appl. Physiol. 8: 73-80, 1955.

von Döbeln, W., I. Åstrand and A. Bergstrom. An analysis of age and other factors related to maximal oxygen uptake. J. Appl. Physiol. 22(5): 934-938, 1967.

Wahlund, H. Determinationof the physical working capacity. Acta Med. Scand. Suppl. 215: 1-78, 1948.

Wasserman, K., and M. B. McIlroy. Detecting the Threshold of Anaerobic Metabolism in Cardiac Patients during exercise. The Am. J. of Cardiol. 14: 844-852, 1964.

Welch, B. E., R. P. Riendeau, C. E. Crisp and R. S. Isenstein. Relationship of maximal oxygen consumption to various components of body composition. J. Appl. Physiol. 12: 395-398, 1958.

Wyndham, C. H., N. B. Strydom and W. P. Leary. Studies of the maximum capacity of men for physic al effort. Part II: The maximum oxygen intakes of young, active Caucasians. Int. Z. angew Physiol. einschl. Arbeitsphysiol. 22: 296-303, 1966. a.

Wyndham, C. H., N. B. Strydom, W. P. Leary and C. G. Williams. Studies of the maximum capacity of men for physical effort. Part I: A comparison of methods of assessing maximum oxygen intake. Int. Z. angew Physiol. einschl. Arbeitsphysiol. 22: 285-295, 1966. b.

APPENDIX 1

TEST CONDITIONS (BICYCLE): Subject's weight (WGT, kg), barometric pressure (BP, mm Hg), ambient temperature (TEMP, C), warm-up oxygen uptake (WUMK, ml/kg/min), time to exhaustion (TIM, min) and final work rate (FWR, kgm/min) for five male subjects at the pedalling frequencies shown in the left-hand column.

TEST	SUBJ	WGT	BP	TEMP	WUMK	TIM	FWR
60 RPM	VP	96.78	736.0	22.0	33.2	8.0	1879
	MC	80.13	736.4	21.4	41.4	8.0	2158
	BN	76.48	737.3	21.2	43.0	9.0	2376
	BC	76.05	735.0	22.1	43.7	8.0	2123
	JH	70.43	739.1	22.1	42.7	10.0	2376
80 RPM	VP	96.58	736.5	22.8	34.0	8.0	2086
	MC	78.90	735.4	20.9	41.5	7.5	2112
	BN	76.38	739.6	21.5	43.9	9.0	2370
	BC	76.30	738.3	22.6	46.7	8.5	2460
	JH	69.90	741.6	22.6	42.6	9.0	2370
100 RPM	VP	96.63	730.4	21.6	33.9	6.5	2100
	MC	78.85	727.0	21.5	42.4	7.0	1974
	BN	77.10	734.3	21.9	42.8	9.0	2376
	BC	75.65	740.2	22.7	46.5	8.0	2058
	JH	71.05	737.4	23.1	41.2	9.0	2448
120 RPM	VP	97.80	731.4	20.8	35.4	5.0	1695
	MC	79.18	728.8	23.6	43.2	5.0	1770
	BN	77.25	738.4	22.2	44.2	7.6	2053
	BC	75.85	733.4	25.4	42.5	6.0	1800
	JH	70.48	739.2	24.1	42.4	8.0	2088

APPENDIX 2

TEST CONDITIONS (TREADMILL): Subject's weight (WGT, kg), barometric pressure (BP, mm Hg), ambient temperature (TEMP, C), warm-up oxygen uptake (WUMK, ml/kg/min), time to exhaustion (TIM, min) and final work rate (FWR, % grade) for five male subjects at the running speeds shown in the left-hand column.

TEST	SUBJ	WGT	BP	TEMP	WUMK	TIM	FWR
6.0 MPH	VP	97.00	736.3	21.4	33.4	7.0	15.0
	MC	79.58	739.5	22.6	40.4	8.0	17.5
	BN	76.98	736.9	22.7	43.0	9.8	22.5
	BC	76.18	732.4	25.4	43.2	9.0	20.0
	JH	70.35	736.8	23.5	41.7	10.5	25.0
6.5 MPH	VP	95.73	733.7	24.4	34.4	6.0	12.5
	MC	79.30	735.6	21.7	41.2	7.5	17.5
	BN	78.03	734.6	21.6	42.5	8.5	20.0
	BC	76.30	738.6	21.9	44.6	8.7	20.0
	JH	70.75	736.4	22.2	41.8	9.5	22.5
7.0 MPH	VP	96.10	737.7	21.3	34.8	5.4	12.5
	MC	78.70	735.9	21.8	43.0	7.0	15.0
	BN	76.83	738.3	21.2	42.6	8.0	17.5
	BC	76.10	738.3	22.4	44.9	8.0	17.5
	JH	70.28	741.3	22.4	43.0	9.0	20.0
7.5 MPH	VP	97.48	734.6	21.9	33.4	5.0	10.0
	MC	78.93	731.3	21.3	39.5	6.5	15.0
	BN	77.40	727.5	21.5	43.3	6.3	15.0
	BC	75.98	740.1	22.5	45.1	7.5	17.5
	JH	70.80	734.1	26.8	40.7	8.3	20.0

APPENDIX 3

WARM-UP HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for the 2nd through 6th minutes of warm-up for five male subjects prior to exhaustive exercise on the bicycle ergometer at the pedalling frequencies shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		2	3	4	5	6	2	3	4	5	6
60 RPM	VP	129	136	141	143	146	47.7	85.0	99.5	102.6	103.5
	MC	127	136	141	143	143	51.4	81.5	93.0	94.4	97.5
	BN	127	135	138	139	138	50.1	96.9	94.0	100.3	100.8
	BC	127	137	141	143	150	43.6	80.7	92.3	97.5	98.9
	JH	128	133	134	139	138	40.8	68.2	72.9	74.9	75.4
80 RPM	VP	130	138	143	148	150	49.5	90.8	106.4	112.5	115.6
	MC	123	131	141	139	146	48.5	78.2	90.9	93.9	96.9
	BN	132	136	138	144	145	55.0	91.0	98.3	101.3	102.2
	BC	134	143	147	147	152	48.9	81.6	92.5	93.0	102.4
	JH	130	138	140	142	141	44.8	67.5	77.7	77.3	76.6
100 RPM	VP	127	134	138	143	145	47.6	87.0	99.5	106.7	108.7
	MC	129	136	141	144	144	56.3	80.1	96.8	99.9	102.9
	BN	133	138	138	145	145	64.4	89.7	98.0	102.1	104.2
	BC	136	144	145	147	150	50.0	80.2	84.5	85.0	92.6
	JH	129	136	136	136	141	40.4	68.5	75.2	73.8	76.6
120 RPM	VP	130	141	143	150	154	63.8	89.3	103.9	114.4	116.4
	MC	127	140	145	146	148	53.6	79.9	94.6	94.3	100.5
	BN	123	132	134	134	136	57.4	95.5	106.4	105.7	114.1
	BC	129	138	144	145	146	43.1	81.7	94.2	96.4	95.3
	JH	130	132	132	132	135		66.5	72.3	75.3	77.3

APPENDIX 4

WARM-UP HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for the 2nd through 6th minutes of warm-up for five male subjects prior to exhaustive exercise on the treadmill at the running speeds shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		2	3	4	5	6	2	3	4	5	6
6.0 MPH	VP	129	139	142	148	149	49.8	88.1	99.5	106.8	105.6
	MC	105	125	130	132	138	47.3	73.7	84.7	89.9	98.8
	BN	124	136	138	138	143	65.3	93.2	100.5	100.8	101.8
	BC	135	138	144	146	148	50.8	84.6	94.8	98.2	98.5
	JH	131	138	137	140	144	46.4	69.7	76.8	75.4	76.6
6.5 MPH	VP	118	139	141	146	149	54.5	103.3	113.3	119.4	120.3
	MC	128	138	141	144	145	44.0	80.1	94.2	102.0	99.8
	BN	129	138	139	141	143	61.5	90.1	97.2	104.6	103.4
	BC	132	144	146	146	148	48.0	81.5	89.8	93.9	98.9
	JH	131	133	127	136	138	41.6	66.0	73.3	72.1	74.8
7.0 MPH	VP	129	135	141	147	149	73.7	91.4	103.7	112.1	116.2
	MC	132	140	144	145	143	52.8	78.2	89.8	93.9	98.0
	BN	126	132	137	138	141	76.0	95.0	99.6	99.5	101.1
	BC		137	138	137	146	47.3	80.6	92.1	94.6	96.2
	JH	132	138	138	142	143	43.1	70.6	75.8	78.7	76.3
7.5 MPH	VP	129	139	143	148	149	61.6	89.0	99.3	101.9	110.6
	MC	124	131	138	143	144	52.8	78.7	89.0	96.3	96.2
	BN	128	135	136	136	141	61.8	94.1	100.7	100.6	106.8
	BC	131	140	143	145	148	46.6	72.2	88.4	92.9	96.6
	JH	133	143	144	146	148	42.1	68.5	73.9	74.9	78.0

APPENDIX 5

EXHAUSTIVE EXERCISE HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for five male subjects for the last five minutes of exhaustive exercise on the bicycle ergometer at the pedalling frequencies shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		L-4	L-3	L-2	L-1	L	L-4	L-3	L-2	L-1	L
60 RPM	VP	153	161	167	171	176	115.1	127.3	148.6	171.9	196.2
	MC	155	164	173	177	181	94.4	111.1	130.1	169.1	177.4
	BN	157	161	166	173	179	104.7	118.2	133.4	153.3	177.5
	BC	158	162	167	171	177	102.1	116.7	118.5	149.2	152.2
	JH	175	182	188	196	198	114.0	128.3	151.1	171.7	175.4
80 RPM	VP	155	162	167	173	181	113.5	133.4	155.3	171.9	207.7
	MC	161	169	173	178	182	101.1	119.0	132.5	170.8	190.9
	BN	161	164	170	176	180	119.9	139.9	153.3	180.7	210.3
	BC	170	173	180	184	186	119.5	127.3	161.5	177.2	153.1
	JH	173	180	185	188	196	114.0	128.7	140.6	150.6	178.7
100 RPM	VP	152	159	166	170	171	118.4	144.6	159.1	185.2	196.8
	MC	155	167	173	177	180	103.6	134.9	149.2	171.2	175.4
	BN	166	167	171	176	182	128.0	141.5	166.6	185.5	217.0
	BC	163	170	174	181	185	109.2	120.3	138.0	165.2	186.3
	JH	177	182	187	19[illegible]	198	118.8	136.5	151.2	162.6	182.0
120 RPM	VP	150	158	167	171	176	59.3	117.7	159.8	184.1	195.4
	MC	158	165	173	175	181		118.7	149.0	173.2	194.0
	BN	159	166	168	172	173	142.3	162.7	183.7	192.9	195.0
	BC	164	168	175	180	185	124.1	147.5	159.9	184.1	174.4
	JH	178	184	189	195	196	130.7	141.8	154.3	171.5	179.1

APPENDIX 6

EXHAUSTIVE EXERCISE HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for five male subjects for the last five minutes of exhaustive exercise on the treadmill at the running speeds shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		L-4	L-3	L-2	L-1	L	L-4	L-3	L-2	L-1	L
6.0 MPH	VP	158	164	170	177	181	114.2	126.6	149.7	160.0	197.8
	MC	161	170	173	181	184	114.0	127.1	138.9	156.7	168.5
	BN	170	176	180	180	184	131.9	150.8	172.5	191.3	186.3
	BC	168	175	178	184	186	115.5	133.8	144.1	169.2	181.2
	JH	183	193	196	200	202	118.6	133.4	151.6	159.4	175.7
6.5 MPH	VP	150	158	167	173	177	102.8	118.3	134.9	150.4	176.6
	MC	173	176	179	185	186	117.6	134.4	145.8	176.8	170.8
	BN	167	173	178	181	182	129.4	150.2	177.2	189.8	193.7
	BC	173	177	182	184	187	124.5	140.0	163.4	175.6	180.4
	JH	182	189	195	198	200	104.7	138.4	144.5	154.6	172.5
7.0 MPH	VP	143	153	163	170	177	68.8	109.9	133.0	157.4	178.8
	MC	166	171	176	180	184	105.4	124.3	139.0	156.7	172.6
	BN	158	165	173	177	181	111.5	156.2	156.5	171.1	190.7
	BC	168	175	178	184	187	113.5	127.1	142.6	165.6	179.1
	JH	177	182	191	196	200	111.5	124.0	138.6	149.9	160.3
7.5 MPH	VP	145	158	169	176	182	74.9	116.0	141.1	157.6	182.9
	MC	169	176	179	184	185	120.6	135.7	160.3	176.0	167.0
	BN	156	164	173	176	180	114.7	128.2	145.0	172.0	193.1
	BC	170	172	178	183	184	120.4	138.9	165.1	173.4	171.3
	JH	177	180	192	196	200	99.1	113.9	114.9	147.5	159.0

APPENDIX 7

RECOVERY HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for five male subjects for five minutes of recovery following exhaustive exercise on the bicycle ergometer at the pedalling frequencies shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		1	2	3	4	5	1	2	3	4	5
60 RPM	VP	148	125	111	102	100	147.4	86.1	62.9	54.4	41.7
	MC	146	130	123	114	106	141.5	107.3	91.1	72.7	67.5
	BN	157	124	109	101	100	151.1	108.2	73.9	63.3	53.8
	BC	142	114	96	96	100	131.2	82.2	44.2	35.7	33.2
	JH	168	138	123	117	106	158.3	107.2	84.4	67.9	61.6
80 RPM	VP	153	128	118	102	101	163.4	109.9	71.0	62.6	52.6
	MC	150	122	113	108	104	137.9	113.8	86.2	68.3	47.0
	BN	158	132	113	109	103	166.7	123.8	90.1	64.8	66.9
	BC	145	120	111	101	106	151.5	89.7	60.0	54.2	48.9
	JH	172	142	124	115	115	147.1	95.3	74.9	61.9	67.8
100 RPM	VP	143	119	104	98	99	158.0	92.5	57.6	53.4	48.2
	MC	124	115	107	103	100	131.1	99.7	73.4	60.7	50.1
	BN	162	130	115	113	106	171.1	123.4	94.1	74.1	66.7
	BC	155	129	110	110	105	137.8	93.6	56.7	54.9	43.3
	JH	170	140	127	121	116	142.2	104.3	83.6	75.3	64.9
120 RPM	VP	136	122	115	107	103	152.0	103.3	71.5	54.6	42.9
	MC	142	128	115	107	108	149.9	115.2	88.8	80.5	61.5
	BN	145	110	103	103	93	154.3	111.4	90.9	71.5	55.8
	BC	152	114	111	108	100	152.3	100.0	62.7	52.2	48.1
	JH	165	144	128	122	115	162.0	107.6	92.4	76.6	67.2

APPENDIX 8

RECOVERY HEART RATE AND VENTILATION: Heart rate (BPM) and ventilation (STPD, L/MIN) for five male subjects for five minutes of recovery following exhaustive exercise on the treadmill at the running speeds shown in the left-hand column.

TEST	SUBJ	HEART RATE					VENTILATION				
		1	2	3	4	5	1	2	3	4	5
6.0 MPH	VP	149	120	110	101	100	155.8	106.3	82.0	68.3	54.5
	MC	129	108	106	98	100		107.7	84.6	69.8	61.4
	BN	143	110	105	93	91	155.2	119.2	89.9	84.8	64.9
	BC	150	112	110	95	92	146.5	110.9	93.6	59.5	47.5
	JH	176	148	130	122	114	143.5	123.6	105.9	94.9	72.8
6.5 MPH	VP	137	112	96	90	90	132.9	102.3	59.2	52.9	48.7
	MC	144	123	110	107	106	154.6	109.9	88.9	75.2	73.2
	BN	155	118	105	106	90	162.1	133.8	100.2	77.2	67.8
	BC	144	121	96	93	94	144.9	109.3	77.4	60.5	31.9
	JH	170	142	126	120	110	146.6	115.0	99.4	81.5	47.7
7.0 MPH	VP	139	125	96	92	90	135.9	103.0	81.9	58.6	45.9
	MC	150	112	106	100	99	149.3	105.0	92.5	70.3	62.9
	BN	148	118	94	91	88	153.2	120.8	89.9	68.3	74.8
	BC	151	122	94	94	91	147.4	117.1	78.2	58.2	44.0
	JH	177	148	129	117	108	141.2	127.3	101.7	85.5	61.1
7.5 MPH	VP	145	115	103	101	96	176.9	99.7	74.5	78.8	54.4
	MC	147	116	100	99	95	153.3	115.3	87.2	68.4	60.0
	BN	127	110	100	92	89	146.3	103.2	86.7	70.4	54.6
	BC	138	103	96	98	91	132.7	91.2	60.4	46.8	41.2
	JH	168	142	128	122	118	133.9	11[illegible].0	85.4	74.5	65.1

APPENDIX 9

WARM-UP

Respiratory gas exchange during the last minute of warm-up prior to each bicycle test for five male subjects.

TEST	SUBJ	VENT	VO	VCO	RER	VE	OE
60 RPM	VP	103.5	3.215	3.272	1.02	32.20	3.89
	MC	97.5	3.319	3.505	1.06	29.38	4.26
	BN	100.8	3.288	3.250	0.99	30.66	4.08
	BC	98.9	3.320	3.355	1.01	29.79	4.21
	JH	75.4	3.008	2.621	0.87	25.07	4.98
80 RPM	VP	115.6	3.284	3.540	1.08	35.20	3.56
	MC	96.9	3.275	3.465	1.06	29.59	4.24
	BN	102.2	3.352	3.299	0.98	30.49	4.09
	BC	102.4	3.560	3.343	0.94	28.76	4.34
	JH	76.6	2.974	2.717	0.91	25.75	4.82
100 RPM	VP	108.7	3.271	3.307	1.01	33.23	3.80
	MC	102.9	3.344	3.487	1.04	30.77	4.12
	BN	104.2	3.296	3.275	0.99	31.61	3.97
	BC	92.6	3.519	3.184	0.91	26.31	4.73
	JH	76.6	2.929	2.660	0.91	26.15	4.78
120 RPM	VP	116.4	3.465	3.625	1.05	33.59	3.75
	MC	100.5	3.418	3.678	1.08	29.40	4.31
	BN	114.1	3.412	3.546	1.04	33.44	3.73
	BC	95.3	3.222	3.138	0.97	29.58	4.25
	JH	77.3	2.990	2.617	0.88	25.85	4.82

VENT (BTPS, L/MIN) Ventilation
VO (STPD, L/MIN) Oxygen uptake
VCO (STPD, L/MIN) Carbon dioxide produced
RER Respiratory exchange ratio
VE Ventilatory equivalent
OE Percentage oxygen extraction

APPENDIX 10

WARM-UP

Respiratory gas exchange during the last minute of warm-up prior to each treadmill test for five male subjects.

TEST	SUBJ	VENT	VO	VCO	RER	VE	OE
6.0 MPH	VP	105.6	3.236	3.300	1.02	32.63	3.84
	MC	98.8	3.217	3.548	1.10	30.71	4.06
	BN	101.8	3.310	3.259	0.99	30.76	4.07
	BC	98.5	3.293	3.334	1.01	29.91	4.21
	JH	76.6	2.932	2.719	0.93	26.13	4.79
6.5 MPH	VP	120.3	3.296	3.597	1.09	36.50	3.44
	MC	99.8	3.267	3.519	1.08	30.55	4.10
	BN	103.4	3.312	3.253	0.98	31.22	4.02
	BC	98.9	3.404	3.472	1.02	29.05	4.30
	JH	74.8	2.959	2.647	0.90	25.28	4.95
7.0 MPH	VP	116.2	3.343	3.488	1.04	34.76	3.60
	MC	98.0	3.387	3.433	1.01	28.93	4.33
	BN	101.1	3.273	3.038	0.93	30.89	4.04
	BC	96.2	3.419	3.204	0.94	28.14	4.44
	JH	76.3	3.020	2.628	0.87	25.27	4.92
7.5 MPH	VP	110.6	3.255	3.339	1.03	33.98	3.69
	MC	96.2	3.120	3.335	1.07	30.83	4.09
	BN	106.8	3.353	3.378	1.01	31.85	3.98
	BC	96.6	3.428	3.409	0.99	28.18	4.42
	JH	78.0	2.881	2.772	0.96	27.07	4.64

VENT (BTPS, L/MIN) Ventilation
VO (STPD, L/MIN) Oxygen uptake
VCO (STPD, L/MIN) Carbon dioxide produced
RER Respiratory exchange ratio
VE Vertilatory equivalent
OE Percentage oxygen extraction

APPENDIX 12

EXHAUSTIVE EXERCISE

Respiratory gas exchange for either the last or penultimate minute of exhaustive exercise during treadmill running for five male subjects. Values are those of greatest oxygen uptake from either of these minutes.

TEST	SUBJ	VENT	VO	MLKG	VCO	RER	VE	OE
6.0 MPH	VP	197.8	5.169	53.29	6.091	1.18	38.27	3.27
	MC	168.5	4.711	59.20	5.877	1.25	35.77	3.48
	BN	191.3	5.312	69.00	5.951	1.12	36.01	3.47
	BC	181.2	5.026	65.98	6.152	1.22	36.05	3.49
	JH	175.7	4.988	70.90	6.175	1.24	35.23	3.55
6.5 MPH	VP	176.6	4.848	50.64	5.666	1.17	36.43	3.45
	MC	176.8	4.775	60.21	5.787	1.21	37.03	3.39
	BN	193.7	4.992	63.98	6.050	1.21	38.80	3.24
	BC	180.4	5.080	66.58	6.258	1.23	35.51	3.51
	JH	172.5	5.325	75.27	6.211	1.17	32.39	3.86
7.0 MPH	VP	178.8	4.971	51.73	5.433	1.09	35.97	3.47
	MC	172.6	4.580	58.20	5.368	1.17	37.69	3.32
	BN	190.7	5.185	67.49	5.960	1.15	36.78	3.39
	BC	179.1	5.341	70.18	5.944	1.11	33.53	3.72
	JH	160.3	5.211	74.15	5.980	1.15	30.76	4.04
7.5 MPH	VP	182.9	4.936	50.64	5.635	1.14	37.05	3.39
	MC	176.0	4.598	58.25	5.312	1.16	38.28	3.30
	BN	172.0	4.884	63.10	5.777	1.18	35.22	3.60
	BC	173.4	5.354	70.47	5.509	1.03	32.39	3.85
	JH	159.0	4.691	66.26	5.900	1.26	33.90	3.71

VENT (BTPS, L/MIN) Ventilation
VO (STPD, L/MIN) Oxygen uptake
MLKG (STPD, ML/KG/MIN) Oxygen uptake
VCO (STPD, L/MIN) Carbon dioxide produced
RER Respiratory exchange ratio
VE Ventilatory equivalent
OE Percentage oxygen extraction

APPENDIX 13

BLOOD CHEMISTRY

Blood lactate (mg/100 ml), hemoglobin (g/100 ml) and hematocrit following warm-up and during the fifth and eighth minute after exhaustive bicycle ergometry.

TEST	SUBJ	LAWU	LAR5	LAR8	LAMAX	HBWU	HBR5	HEWU	HER5
60 RPM	VP	45.5	109.0	106.5	109.0	16.3	16.5	50.8	50.0
	MC	72.9	153.4	146.8	153.4	14.0	15.8	50.2	52.6
	BN	21.4	111.0	106.0	111.0	14.9	15.5	51.0	51.5
	BC	29.7	95.6	80.4	95.6	15.2	16.0	52.5	53.6
	JH	19.6	138.3	130.4	138.3	13.0	13.3	44.8	48.0
80 RPM	VP	56.4	128.5	126.7	128.5	16.5	16.8	51.1	53.2
	MC	68.0	152.4	133.6	152.4	15.1	16.8	49.6	53.0
	BN	35.0	138.9	152.4	152.4	15.0	15.8	49.6	49.7
	BC	37.9	142.7	133.2	142.7	14.5	14.7	52.5	53.5
	JH	30.5	131.7	123.8	131.7	13.7	14.0	47.8	47.0
100 RPM	VP	53.0	117.1		117.1	15.9	16.4	49.6	50.0
	MC	62.9	140.8	126.1	140.8	15.9	16.2	49.8	53.2
	BN	40.5	147.7	137.4	147.7	15.5	16.2	49.0	50.1
	BC	34.4	128.5	118.6	128.5	14.5	15.2	50.7	55.1
	JH	23.4	144.0	132.7	144.0	13.3	14.0	45.9	48.4
120 RPM	VP	60.5	109.6	110.1	110.1	17.7	18.0	52.0	54.0
	MC	73.6	147.4	147.0	147.4	15.2	16.2	49.8	50.0
	BN	36.5	137.9	143.0	143.0	14.2	15.0	49.5	52.2
	BC	35.9	129.9	129.9	129.9	15.2	15.3	50.8	53.2
	JH	25.2	143.0	134.6	143.0	13.0	13.5	46.1	48.7

LAWU Lactate concentration following warm-up
LAR5 Lactate concentration after five minutes of recovery
LAR8 Lactate concentration after eight minutes of recovery
LAMAX Maximum lactate concentration
HBWU Hemoglobin following warm-up
HBR5 Hemoglobin following five minutes of recovery
HEWU Hematocrit following warm-up
HER5 Hematocrit following five minutes of recovery

APPENDIX 14

BLOOD CHEMISTRY

Blood lactate (mg/100 ml), hemoglobin (g/100 ml) and hematocrit following warm-up and during the fifth and eighth minute after exhaustive treadmill running.

TEST	SUBJ	LAWU	LAR5	LAR8	LAMAX	HBWU	HBR5	HEWU	HER5
6.0 MPH	VP	50.7		107.5	107.5	16.0	16.2		52.3
	MC	68.0	164.7	159.0	164.7	14.2	14.5	50.3	53.5
	BN	30.2	148.7	143.0	148.7	14.0	15.0	50.6	53.1
	BC	42.2	125.1	110.1	125.1	15.2	14.9	52.2	53.4
	JH	25.2	140.2	136.4	140.2	14.1	15.1	48.4	49.2
6.5 MPH	VP	62.0	98.0	88.1	98.0	16.5	16.8	51.1	52.8
	MC	71.1	161.8	161.8	161.8	15.8	16.3	50.4	52.8
	BN	40.0	163.7	161.8	163.7	15.6	16.5	48.5	51.6
	BC	34.0	143.0	129.3	143.0	15.2	15.5	52.5	54.5
	JH	22.6	132.5	127.4	132.5	14.0	14.2	47.7	48.5
7.0 MPH	VP	54.7	116.7	102.9	116.7	16.3	16.5	50.8	51.6
	MC	66.5	152.4	139.3	152.4	14.0	15.2	47.8	50.6
	BN	45.4	144.9	139.6	144.9	14.0	14.3	49.8	50.2
	BC	32.6	126.1	120.8	126.1	14.5	14.6	51.2	52.7
	JH	21.6	148.7	147.7	148.7	13.3	13.5	45.8	48.5
7.5 MPH	VP	57.3	112.6	116.7	116.7	16.3	16.7	51.6	52.5
	MC	68.2	176.0	164.7	176.0	13.7	14.0	49.5	52.0
	BN	39.8	141.1	137.4	141.1	15.3	15.8	49.4	48.9
	BC	44.8		102.6	102.6	15.5	15.9	53.5	54.3
	JH	24.8		133.6	133.6	14.2	14.0	46.4	47.8

LAWU Lactate concentration following warm-up
LAR5 Lactate concentration after five minutes of recovery
LAR8 Lactate concentration after eight minutes of recovery
LAMAX Maximum lactate concentration
HBWU Hemoglobin following warm-up
HBR5 Hemoglobin following five minutes of recovery
HEWU Hematocrit following warm-up
HER5 Hematocrit following five minutes of recovery

APPENDIX 15

PL/1 program for respiratory gas analysis.

```
//A220GMCK JOB (****,*****),'MAXTEST',TIME=1,CLASS=F
// EXEC PL1LFCG
//SYSIN DD *
 MAXTEST:PROC OPTIONS(MAIN);
  /***********************************************************
    ***************
                LIST OF THE TERMS USED IN THIS PROGRAM
                SUBJ  THE SUBJECT USED IN THIS TEST
                DAT   THE DATE OF THE TEST
                DAY   DAY OF THE MONTH
                MO    MONTH
                WGT   THE WEIGHT OF THE SUBJECT
                TEST  THE NUMBER OF THE TEST IN A SERIES OF
    * TESTS
                MIN   THE MINUTE OF THE TEST THAT IS BEING
    *CALCULATED
                VEB   VENTILATION BTPS (L/MIN)
                VES   VENTILATION STPD (L/MIN)
                BP    BAROMETRIC PRESSURE (MM/HG)
                VPE   VAPOUR PRESSURE OF EXPIRED GAS AT BT
                VPA   VAPOUR PRESSURE OF GAS AT AMBIENT TEM
    *PERATURE
                BT    TEMPERATURE OF EXPIRED GAS (BODY TEMP
    *)
                CF    CORRECTION FACTOR FOR FRACTIONS OF OX
    *YGEN
                      CARBON DIOXIDE
                FOW   FRACTION OF OXYGEN (WET)
                FCOW  FRACTION OF CARBON DIOXIDE (WET)
                FOD   FRACTION OF OXYGEN (DRY)
                FCOD  FRACTION OF CARBON DIOXIDE (DRY)
                FIO   FRACTION OF INSPIRED OXYGEN
                FICO  FRACTION OF INSPIRED CARBON DIOXIDE
                FIN   FRACTION OF INSPIRED NITROGEN
                FEO   FRACTION OF EXPIRED OXYGEN = FOD
                FECO  FRACTION OF EXPIRED CARBON DIOXIDE =
    *FCOD
                FEN   FRACTION OF EXPIRED NITROGEN
                VO    OXYGEN UPTAKE (L/MIN)
```

```
              VOPK   OXYGEN UPTAKE PER KILOGRAM OF BODY WG
    *T (ML/KG)
              VCO    CARBON DIOXIDE PRODUCED (L/MIN)
              R      RESPIRATORY QUOTIENT
              VEQU   VENTILATORY EQUIVALENT
              POE    PERCENTAGE OXYGEN EXTRACTED
*********************************************************
    ************/
        DECLARE
           VEB FLOAT ,
           BP  FLOAT ,
           BT  FLOAT ,
           CF  FLOAT ,
           SUBJ CHAR (2),
           (MIN, TEST) DEC FIXED (1),
           (VES,VPE,VPA,FOW,FOD,FIO,FIN,FEO,FEN) FLOAT ,
           (FCOW,FCOD,VO,VCO,FICO,FECO,R) FLOAT ,
           (VOPK,WGT) FLOAT ,
           1 DAT, 2 DAY FIXED (2), 2 MO CHAR(3),
           (VEQU,VOE) FLOAT,
           ;
    GET EDIT (SUBJ,DAY,MO,TEST,WGT,MIN,VEB,BT,VPE,BP,FOW,
    *FCOW,
                 FIO,FICO,VPA)
                (A(2),F(2),A(3),F(1),F(5,2),F(1),F(4,1),
    *F(3,1),F(5,3),
                F(4,1),F(5,5),F(5,5),F(5,5),F(5,5),F(5,3
    *));
         GOTO FIRST;
NEW:    GET EDIT (SUBJ,DAY,MO,TEST,WGT,MIN,VEB,BT,VPE,BP,
    *FOW,FCOW,
                 FIO,FICO,VPA)
                (COL(1),A(2),F(2),A(3),F(1),F(5,2),F(1),
    *F(4,1),F(3,1),
                F(5,3),F(4,1),F(5,5),F(5,5),F(5,5),F(5,5
    *),F(5,3));
FIRST:          PUT PAGE;
        PUT SKIP(5) EDIT('SUBJECT: ',SUBJ,'TEST #',TEST,'
    *MINUTE = ',
        MIN,'DATE: ',MO,DAY)(X(10),A,A(2),X(5),A,F(1),X(5
    *),A,F(1),X(5),
        A,A(3),X(1),F(2));
/********************************************************
    *************
       THE FOLLOWING ARE THE EQUATIONS TO BE USED
```

```
*         */
       VES=VEB*((BP-VPA)/760)*(273/(273+BT));
       CF=BP/(BP-VPA);
       FOD=FOW*CF;
       FCOD=FCOW*CF;
       FEO=FOD;
       FECO=FCOD;
       VO=VES*(FIO*((1.0-FEO-FECO)/(1.0-FIO-FICO))-FEO)
*;
       VOPK=(VO/WGT)*1000;
       VCO=VES*(FECO-(FICO*(1.0-FEO-FECO)/(1.0-FIO-FICO
*)));
       R=VCO/VO;
       VEQU=VES/VO;
       POE=(VO/VES)*100;
/**********************************************************
*************
     FORMAT FOR THE PRINTOUT OF THE RESULTS
*         */
      PUT SKIP(3) EDIT('CORRECTION FACTOR',CF,
          'FRACTION OF OXYGEN (DRY)',
          FOD,'FRACTION OF CARBON DIOXIDE (DRY)',FCOD,
          'WEIGHT OF THE SUBJECT',WGT,'  KG',
          'VENTILATION (STPD)',VES,'  LITERS',
          'OXYGEN UPTAKE IN MINUTE #',MIN,VO,' LITERS',
          VOPK,'  ML/KG',
          'CARBON DIOXIDE PROCUCED IN MINUTE #',MIN,VCO
*,' LITERS',
          'RESPIRATORY EXCHANGE RATIO IS',R,'VENTILATOR
*Y EQUIVALENT',
          VEQU,'PERCENTAGE OXYGEN EXTRACTION',POE)
          (X(30),A,COL(65),F(7,3),SKIP(2),X(30),A,COL(6
*5),F(7,5),
          SKIP(2),X(30),A,COL(65),F(7,5),
          SKIP(4),X(20),A,COL(58),F(6,2),A,
          SKIP(4),X(20),A,COL(58),F(6,2),A,
          SKIP(4),X(20),A,F(1),COL(60),F(5,3),A,SKIP,CO
*L(59),F(5,2),
          A,SKIP(2),X(20),A,F(1),COL(60),F(5,3),A,SKIP(
*2),
          X(20),A,COL(60),F(4,2),SKIP(2),X(20),A,COL(59
*),F(5,2),
          SKIP(2),X(20),A,COL(60),F(5,3));
      GOTO NEW;
       END MAXTEST;
//GO.SYSIN DD *
VP28MAY1 967881850276276967360179920319521416000301982 7
```

APPENDIX 16

Sample output for program shown in Appendix 15.

SUBJECT: VP   TEST #1   MINUTE = 8   DATE: MAY 28

CORRECTION FACTOR	1.028
FRACTION OF OXYGEN (DRY)	0.18490
FRACTION OF CARBON DIOXIDE (DRY)	0.03283

WEIGHT OF THE SUBJECT	96.78	KG
VENTILATION (STPD)	158.33	LITERS
OXYGEN UPTAKE IN MINUTE #8	4.491	LITERS
	46.40	ML/KG
CARBON DIOXIDE PROCUCED IN MINUTE #8	5.151	LITERS
RESPIRATORY EXCHANGE RATIO IS	1.15	
VENTILATORY EQUIVALENT	35.25	
PERCENTAGE OXYGEN EXTRACTION	2.837	

APPENDIX 17

SPSS program for statistical analysis of data.

```
//GAMSPSSS JOB (XXXX,GXXXX),'GET DATA',MSGCLASS=R
/*JOBPARM  LINES=40,PSWD=XXX
// EXEC SPSS,INFILE='SC.A0447.LAST8'
//FT09F001 DD  SYSOUT=R,DCB=(LRECL=80,BLKSIZE=800,RECFM=FB)
RUN NAME       INDIVIDUAL TESTS
GET FILE       DATA
IF             (HEWU1 GE HEWU2) HEWU=HEWU1
IF             (HEWU2 GT HEWU1) HEWU=HEWU2
IF             (HER51 GE HER52) HER5=HER51
IF             (HER52 GT HER51) HER5=HER52
IF             (LAWU1 GE LAWU2) LAWU=LAWU1
IF             (LAWU2 GT LAWU1) LAWU=LAWU2
IF             (LAR51 GE LAR52) LAR5=LAR51
IF             (LAR52 GT LAR51) LAR5=LAR52
IF             (LAR81 GE LAR82) LAR8=LAR81
IF             (LAR82 GT LAR81) LAR8=LAR82
IF             (LAR5 GE LAR8) LAREX=LAR5
IF             (LAR8 GT LAR5) LAREX=LAR8
IF             (VONL GE VOL) VO=VONL
IF             (VOL GT VONL) VO=VOL
COMPUTE        MLKG=(VO*1000)/WGT
IF             (VO EQ VONL) VEX=VEX2
IF             (VO EQ VOL) VEX=VEX1
IF             (VO EQ VONL) VCO=VCONL
IF             (VO EQ VOL) VCO=VCOL
COMPUTE        RERWU=VCOWU/VOWU
COMPUTE        VEQUWU=VWU6/VOWU
COMPUTE        OXEXTWU=(VOWU/VWU6)*(863.003/(BPA-47.1))*100
COMPUTE        RER=VCO/VO
COMPUTE        VEQU=VEX/VO
COMPUTE        OXEXT=(VO/VEX)*(863.003/(BPA-47.1))*100
*SELECT IF     (TEST EQ 1 OR 2 OR 3 OR 4)
TASK NAME      BIKE TESTS
MARGINAL       VO
OPTIONS        5
STATISTICS     ALL
*SELECT IF     (TEST EQ 5 OR 6 OR 7 OR 8)
TASK NAME      TREADMILL TESTS
MARGINAL       VO
OPTIONS        5
STATISTICS     ALL
*SELECT IF     (TEST EQ 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8)
TASK NAME      LAST EIGHT TESTS
MARGINAL       VO
OPTIONS        5
STATISTICS     ALL
FINISH
/*
```

APPENDIX 18

Output from the sample SPSS program shown in Appendix 17.

```
STATISTICAL PACKAGE FOR THE SOCIAL SCIENCES SPSSH - VERSION 5.02
    *        07/03/75          PAGE     1

      RUN NAME          INDIVIDUAL TESTS
      GET FILE          DATA


                FILE DATA      HAS   58 VARIABLES

                THE SUBFILES ARE..

                              NO OF
                NAME          CASES

                DATA            45


      IF                (HEWU1 GE HEWU2) HEWU=HEWU1
      IF                (HEWU2 GT HEWU1) HEWU=HEWU2
      IF                (HER51 GE HER52) HER5=HER51
      IF                (HER52 GT HER51) HER5=HER52
      IF                (LAWU1 GE LAWU2) LAWU=LAWU1
      IF                (LAWU2 GT LAWU1) LAWU=LAWU2
      IF                (LAR51 GE LAR52) LAR5=LAR51
      IF                (LAR52 GT LAR51) LAR5=LAR52
      IF                (LAR81 GE LAR82) LAR8=LAR81
      IF                (LAR82 GT LAR81) LAR8=LAR82
      IF                (LAR5 GE LAR8) LAREX=LAR5
      IF                (LAR8 GT LAR5) LAREX=LAR8
      IF                (VONL GE VOL) VO=VONL
      IF                (VOL GT VONL) VO=VOL
      COMPUTE           MLKG=(VO*1000)/WGT
      IF                (VO EQ VONL) VEX=VEX2
      IF                (VO EQ VOL) VEX=VEX1
      IF                (VO EQ VONL) VCO=VCONL
      IF                (VO EQ VOL) VCO=VCOL
      COMPUTE           REPWU=VCOWU/VOWU
      COMPUTE           VEQUWU=VWU6/VOWU
```

```
      COMPUTE           OXEXTWU=(VOWU/VWU6)*(863.003/(BPA-47.1))*
    *100
      COMPUTE           RER=VCO/VO
      COMPUTE           VEQU=VEX/VO
      COMPUTE           OXEXT=(VO/VEX)*(863.003/(BPA-47.1))*100
      *SELECT IF        (TEST EQ 1 OR 2 OR 3 OR 4)
      TASK NAME         BIKE TESTS
      MARGINAL          VO
      OPTIONS           5
      STATISTICS        ALL
INDIVIDUAL TESTS                        07/03/75        PAGE    2
BIKE TESTS
FILE   DATA     (CREATION DATE = 05/27/75)

VARIABLE   VO

MEAN          4.625      STD ERROR    0.058     MEDIAN      4.692

MODE          4.970      STD DEV      0.257     VARIANCE    0.066

KURTOSIS     -1.092      SKEWNESS    -0.257     RANGE       0.792

MINIMUM           4.178        MAXIMUM           4.970

VALID   OBSERVATIONS -        20
MISSING OBSERVATIONS -         0   OR    0.0 PERCENT OF TOTAL

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
INDIVIDUAL TESTS                        07/03/75        PAGE    3
BIKE TESTS


 **** GIVEN SPACE ALLOWS FOR   1 VARIABLES AND  3071 VALUES FO
    *R MARGINALS ****


                    *SELECT IF        (TEST EQ 5 OR 6 OR 7 OR 8)
                    TASK NAME         TREADMILL TESTS
                    MARGINAL          VO
                    OPTIONS           5
                    STATISTICS        ALL
INDIVIDUAL TESTS                        07/03/75        PAGE    4
TREADMILL TESTS
FILE   DATA     (CREATION DATE = 05/27/75)
```

```
VARIABLE   VO

MEAN          4.999      STD ERROR    0.055    MEDIAN       4.990

MODE          4.691      STD DEV      0.248    VARIANCE     0.061

KURTOSIS     -1.090      SKEWNESS    -0.126    RANGE        0.774

MINIMUM           4.580         MAXIMUM          5.354

VALID   OBSERVATIONS -         20
MISSING OBSERVATIONS -          0   OR    0.0 PERCENT OF TOTAL
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
INDIVIDUAL TESTS                         07/03/75          PAGE    5
TREADMILL TESTS


 **** GIVEN SPACE ALLOWS FOR   1 VARIABLES AND  3071 VALUES FO
    *R MARGINALS ****


      *SELECT IF        (TEST EQ 1 OR 2 OR 3 OR 4 OR 5 OR 6 OR 7
   * OR 8)
      TASK NAME         LAST EIGHT TESTS
      MARGINAL          VO
      OPTIONS           5
      STATISTICS        ALL
INDIVIDUAL TESTS                         07/03/75          PAGE    6
LAST EIGHT TESTS
FILE    DATA       (CREATION DATE = 05/27/75)


VARIABLE   VO

MEAN          4.812      STD ERROR    0.050    MEDIAN       4.811

MODE          4.970      STD DEV      0.313    VARIANCE     0.098

KURTOSIS     -0.612      SKEWNESS    -0.141    RANGE        1.176

MINIMUM           4.178         MAXIMUM          5.354

VALID   OBSERVATIONS -         40
```

```
MISSING OBSERVATIONS -          0  OR    0.0 PERCENT OF TOTAL
-----------------------------------------------------------------
INDIVIDUAL TESTS                          07/03/75          PAGE     7
LAST EIGHT TESTS

 **** GIVEN SPACE ALLOWS FOR    1 VARIABLES AND  3071 VALUES FO
    *R MARGINALS ****

                    FINISH
INDIVIDUAL TESTS                          07/03/75          PAGE     8
LAST EIGHT TESTS

   NORMAL END OF JOB.
   43 CONTROL CARDS WERE PROCESSED.
    0 ERRORS WERE DETECTED.
```

```
//GAMBMD8V JOB (XXXX,GXXXX),'ANOVA',MSGCLASS=R
/*JOBPARM  LINES=40,PSWD=XXX
//STEP1 EXEC BMD,NAME=BMD08V
//SYSIN DD *
PROBLMEXVO    1 3 1 1
INDEX   5  2  4                              2   4
DESIGN SET        $S,$E,$T(E).
(1F5.3)
4.491
4.674
4.425
4.562
5.169
4.848
4.971
4.936
4.309
4.329
4.178
4.186
4.711
4.775
4.580
4.598
4.470
4.808
4.814
4.757
5.312
4.992
5.185
4.884
4.474
4.755
4.970
4.723
5.026
5.080
5.341
5.354
4.970
4.949
4.710
4.945
4.988
5.325
5.211
4.691
FINISH
/*
```

APPENDIX 19

BMD08V program for two way analysis of variance.

APPENDIX 20

Sample output for the BMD08V program shown in Appendix 19.

```
BMD08V - ANALYSIS OF VARIANCE - REVISED FEBRUARY 19, 1971
HEALTH SCIENCES COMPUTING FACILITY, UCLA


PROBLEM CODE EXVO

INDEX                  S     E     T
NUMBER OF LEVELS       5     2     4
POPULATION SIZE      INF     2     4

DESIGN CARD        SET        $S,$E,$T(E).

VARIABLE FORMAT      (1F5.3)
ANALYSIS OF VARIANCE FOR DEPENDENT VARIABLE  1

    SOURCE      ERROR TERM       F     SUM OF SQUARES DEG. OF
                                                      FREEDOM

 1 MEAN         S           ********    926.1721          1
 2 S                                    1.486220          4
 3 E            SE           45.5164    1.398016          1
 4 T(E)         ST(E)         0.8833    .1476278          6
 5 SE                                   .1228580          4
 6 ST(E)                                .6685371         24


                         MEAN SQUARE    EXPECTED MEAN SQUARE

 1 MEAN                  926.1721       40.000( 1)    8.000( 2)
 2 S                     .3715551        8.000( 2)
 3 E                     1.398016       20.000( 3)    4.000( 5)
 4 T(E)                  .2460464E-01    5.000( 4)    1.000( 6)
 5 SE                    .3071451E-01    4.000( 5)
 6 ST(E)                 .2785571E-01    1.000( 6)
```

ESTIMATES OF VARIANCE COMPONENTS

(1) 23.14500
(2) 0.4644439E-01
(3) 0.6836504E-01
(4) -0.6502150E-03
(5) 0.7678628E-02
(6) 0.2785571E-01

MEAN 4.81189

CELL MEANS

S =	1	2	3	4	5
	4.75949	4.45824	4.90274	4.96537	4.97362

E =	1	2
	4.62494	4.99884

	T =	1	2	3	4
E =	1	4.54279	4.70300	4.61940	4.63460
	2	5.04119	5.00400	5.05760	4.89260

CELL DEVIATIONS

X(S..) - X(...)

S =	1	2	3	4	5
	-0.05240	-0.35365	0.09085	0.15348	0.16173

X(.E.) - X(...)

E =	1	2
	-0.18695	0.18695

X(.ET) - X(.E.)

	T =	1	2	3	4
E =	1	-0.08215	0.07805	-0.00555	0.00965
	2	0.04235	0.00515	0.05875	-0.10625

APPENDIX 21

Previous methods of maximum oxygen uptake determination.

AUTHORS	YEAR	MODE OF TESTING B	T	OTHER	PARTICULARS
Åstrand and Saltin	1961	x			50 rpm, constant.
Balke and Ware	1959		x		3.3 mph (↑ 1%/min), continuous.
Bobbert	1960		x	cranking	60 rpm, walking.
Cunningham and Faulkner	1969		x		7 mph (↑ 2.5%), discontinuous.
Davies _et al_.	1970	x			60 rpm, continuous.
Glassford _et al_.	1965	x	x		50 rpm, 7 mph (↑ 2.5%), discontinuous.
Gleser and Vogel	1973	x			40 - 80 rpm (subject's choice), discontinuous.
Hanson	1973		x		6 mph (14%), 8 mph (17.6%, 21.3%, 25%), discont.
Hermansen _et al_.	1970	x	x		
Hermansen and Saltin	1969	x	x		50 rpm, TM-Taylor et al. (1955), discontinuous.
Horvath and Michael	1970	x			50 rpm, continuous, constant, women.

AUTHORS	YEAR	MODE OF TESTING B	T	OTHER	PARTICULARS
Ikai *et al*.	1971	x			60 rpm, continuous.
Kamon and Pandolf	1972	x	x	laddermill	60 rpm, constant; 7 mph (M), 6 mph (F), (↑ 2.5%) disontinuous.
Karlsson and Saltin	1970	x			60 rpm, constant.
Kasch *et al*.	1966		x	stepping	level, 1-2 mph, continuous.
Katch *et al*.	1973	x			60 rpm, continuous.
Maksud and Coutts	1971		x		7 mph (↑ 2.5%/min), continuous, discontinuous.
McArdle *et al*.	1973	x	x		60 rpm, walk 3.4 mph (0-22%), run 6 mph (↑ 2.5%), continuous, discontinuous.
McArdle and Magel	1970	x	x		60 rpm, walk 3.4 mph (↑ 2%; 1%/min), continuous.
McDonough *et al*.	1970		x		multistage test (2.5 mph, 12%)(3.4 mph, 14%) (4.2 mph, 10%) (5.0 mph, 18%)
Mitchell *et al*.	1958		x		6 mph (↑ 2.5%), intermittent.
Miyamura and Honda	1972	x	x		60 rpm; 9-10.2 km/h, 8.6% (↑ 10 m/min), constant, increment.

AUTHORS	YEAR	MODE OF TESTING			PARTICULARS
		B	T	OTHER	
Nagle et al.	1971	x	x	stepping	50 rpm, 3.0 mph (↑ 2.5%/2 min), continuous.
Newton	1963	x	x		50 rpm, 5.4 km/h (↑ 1%/min), 10 mph (8.6%), continuous.
Robinson	1938		x		8.6% (speed selected to exhaust in 2-5 min)
Shephard et al.	1968	x	x	stepping	60-90 rpm, 8-9.6 mph (1%-18%), continuous, discontinuous.
Taguchi et al.	1971	x	x		50, 60 rpm; walk 3.4 mph (↑ 1%/min), continuous.
Taylor et al.	1955		x		7 mph (↑ 2.5%/day), discontinuous.
von Döbeln et al.	1967	x			50 rpm, continuous.
Wahlund	1948	x			60 rpm, continuous.
Welch et al.	1958		x		6%, 8.5%, 11%, discontinuous.
Wyndham et al.	1966	x	x	stepping	B - discontinuous, TM (↑ mph) continuous and discontinuous.