A SIMPLE TECHNIQUE FOR MEASURING MAXIMUM AEROBIC CAPACITY AND ITS RELATION TO STATE OF TRAINING

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Sean Matthew Donohue
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ABSTRACT

In the past maximum aerobic power tests have been the standard means for measuring the trained state. Recent literature, however, states that the ability to work aerobically at a high percentage of one's maximum aerobic power, referred to as maximum aerobic capacity, may be an equally effective means for indicating a person's state of training. The purpose of this study was to develop a simple technique to measure maximum aerobic capacity and relate this value to the person's state of training.

Twenty trained and twenty untrained subjects ranging in age from 18 to 42 years participated in the study. Participants who accumulated in excess of an average of fifty Cooper points per week were considered as being trained. A re-test was administered to establish the reliability of using ventilation for measuring maximum aerobic capacity.

The trained participants had a significantly greater mean level of maximum aerobic capacity than the untrained participants. Maximum aerobic power values correlated significantly with maximum aerobic capacity values, and maximum aerobic power and the participant's age had a significantly greater correlation than maximum aerobic capacity and the participant's age.

There was no evidence that the maximum aerobic capacity test was any less efficient than the maximum aerobic power test for separating out levels of training, but the former was much easier to administer. Since maximum aerobic capacity was less related to age than maximum aerobic power it might be a better test for evaluating a person's state of training.

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INTRODUCTION

Statement of the Problem

The purpose of this study was to develop a simple technique for determining maximum aerobic capacity (MAC), using the departure from linearity of ventilation rate, and to demonstrate its effectiveness as an indicator of level of training.

Significance

The measurements of maximum aerobic power (MAP) is the most widely used test for assessing an individual's endurance fitness. Testing MAP is time consuming and requires expensive laboratory equipment. A coach may not always have access to facilities of this nature, therefore, testing would be facilitated if there was a simple, inexpensive procedure for measuring an individual's endurance fitness.

An easily repeatable physical endurance test that indicates the athlete's level of training without having to produce a maximum effort is more advantageous to a coach than the MAP test.

Submaximal tests have been used to predict a person's MAP but these are only predictive and are subject to a slight margin of error (±10%).

Values attained on MAP tests are affected by the individual's genetic characteristics and may not be a true indication of the state of training. It has been demonstrated that success in distance running is dependent on the ability to utilize a high percentage of MAP (Costill, & Winrow, 1970).

Bailey (1975) suggested the design of a simple recording system for measuring maximum aerobic capacity (MAC). To date there has not been a simple procedure of this nature developed for measuring MAC using only the departure from linearity in ventilation. A simple, non-invasive test like this could be used by coaches and physical educators to assess the degree to which a person has been trained.

The purpose of this study was to develop a simple technique using the departure from linearity in ventilation rate to measure maximum aerobic capacity. It was also intended to see if the developed maximum aerobic capacity test gave a better indication of training than the maximum aerobic power test which has a large genetic component.

Delimitations

1) The subjects of this study were 40 males ranging in age from 19 to 42 years. An attempt was made to use subjects either highly trained or relatively sedentary.

2) The independent variable studied was the present level of training (trained, untrained).

3) The dependent variable was the subject's MAC.

4) MAC was measured with a volumeter and recorded by an electric graph recorder.

Limitations

1) Due to the stress involved in MAP testing it was necessary to use volunteers for this study.

2) The subjects were required to subjectively record the average number of aerobic points they accumulated per week.

Definitions

Maximum Aerobic Capacity (MAC) is the highest rate of work which can be performed by purely oxidative means without the accumulation of lactic acid and the onset of fatigue (Davies, 1968).

Maximum Aerobic Power (MAP) is the ability of the oxygen transport system to take up, transport, and give off oxygen to the working muscle (Astrand, 1956). It is achieved when, with a further increase in work load, the oxygen consumption increases by less than 2 ml/kg/min.

Anaerobic Threshold (AT) is the level of work or oxygen consumption below which a subject may perform for prolonged periods without increasing blood lactate above the resting level (Bailey, 1975). At this point the rate of accumulation of lactate exceeds the rate of utilization and removal (MacDougall, 1977).

Level of Training was established according to the average number of aerobic points per week the individual accumulated during the four weeks prior to the testing. An individual accumulating an average of more than 50 points per week was considered in the excellent category (Cooper, 1977).

Chapter 2

REVIEW OF LITERATURE

Testing an individual's physical work capacity in the past usually required elaborate and expensive laboratory apparatus. Some authors (Astrand, & Rhyming, 1954; Davies, 1968; Shapiro, A., Shapiro, Y., & Magazanik, 1976; and Wasserman, Whipp, et al, 1973) suggested a need to escape this trend and develop a simple method of testing an individual's level of fitness.

The MAP test was considered to be the best criterion for assessing the ability to do work (Larson, 1967; Shephard, Allen et al, 1968; and Wilmore, 1977) but the test had a tendency to cause undue stress on the subjects who were not in a conditioned state. Direct measurement techniques used by some investigators (Costill, 1970; Issekutz, & Rodhahl, 1961; Kay, & Shephard, 1969; Klissouras, 1973; Mitchell, Sproule, & Chapman, 1958; and Williams, Wyndham, et al, 1967) to measure lactic acid levels during exercise was a major contributor to the subject's discomfort.

Other authors suggested the development of simple indirect techniques for the evaluation of endurance capacity. Davies (1968) developed an indirect procedure for assessing aerobic capacity using pulse-deficit*. Wasserman, & McIlroy (1964) and Wasserman, Whipp, Koyal, & Beaver (1973) suggested that aerobic capacity, indicated by the anaerobic threshold, was detectable by measurements of the respiratory

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*Pulse-Deficit Index (PDI) the number of heart beats by which the total count during the first half of the exercise falls short of the total count during the second half of the exercise. (6-8 mins.)

gas exchange ratio. More recent investigations (Bailey, 1975; Davis, Vodak, P., et al, 1976; and MacDougall, 1977) have shown that the easiest method for determining aerobic capacity was to locate the anaerobic threshold using the departure from linearity of ventilation during an incremental exercise test.

Bicycle versus Treadmill

There have been conflicting opinions as to which type of ergometer elicited the best results when testing physical work capacity. Kay & Shephard (1969) stated that performance on a bicycle ergometer was limited by local factors (fatigue, weakness and pain in the active muscles) while treadmill running was limited by general factors (general exhaustion, and breathlessness). Anaerobic metabolism was found to occur at a lower percentage of MAP during bicycle exercise (Shephard, Allen, et al, 1968) as a result of the involvement of the small muscle groups (quadriceps) rather than the large muscle groups used in treadmill running (Grimby, 1969).

On the other hand, while investigating the anaerobic threshold for different modes of exercise Davis, Vodak, P., et al, (1976) concluded that there was no significant difference between the anaerobic threshold mean values for leg cycling and treadmill walking.

Anaerobic Threshold: An Index for Measuring MAC

Previous investigations (Costill, Thomason, & Roberts, 1973; Wasserman, & McIlroy, 1964; and Williams, Wyndham, et al, 1967) required direct measurement of blood lactate during exercise to locate the anaerobic threshold, while other investigators, as mentioned previously, used indirect techniques such as pulse-deficit, respiratory gas exchange ratios and the nonlinear increase in ventilation. The anaerobic threshold which marked the onset of anaerobic glycolysis was characterized by an increased lactic acid production (Grimby, 1969; Kay, & Shephard, 1969) and a nonlinear increase in ventilation (Bailey, 1975; Davis, Vodak, P., et al, 1976; Hermansen, & Lange Andersen, 1965; and McIlroy, 1963). MacDougall (1977) stated that lactic acid did accumulate at work intensities less than MAP due to certain muscle fibres contracting anaerobically but the body was capable of utilizing and removing this lactate until the anaerobic threshold was reached.

Williams, Wyndham, et al, (1967) found the oxygen consumption in the untrained and trained state at the anaerobic threshold was 1.8 L/min and 2.4 L/min respectively. This represented maximum aerobic capacities of 50% and 64%. Similar findings showed that the MAC in untrained subjects was approximately 55% of MAP (Ekblom, Astrand, et al, 1968) and 75% of MAP in trained subjects (Nagle, Robinhold, et al, 1970). Costill (1970) found highly trained endurance runners were capable of operating at a MAC of 85% or better while Londeree (1977) found that very sedentary individuals exceeded their anaerobic threshold at intensities representing a very low percentage of their MAP.

The easiest technique for locating the anaerobic threshold was to measure ventilation during an incremental exercise test and locate the point at which the ventilation-work rate curve became nonlinear (Wasserman, Whipp, et al, 1973). Bailey (1975) used a continuous incremental work test on a bicycle ergometer to illustrate the level of work below the point at which ventilation became nonlinear. Ventilation increased linearly with oxygen consumption but when the exercise became more intense, a point was reached where the linear relationship was no longer maintained and a more rapid rate of ventilatory increase than the rate of increase in oxygen consumption was displayed. The point of breakaway ventilation was the point where the anaerobic threshold was exceeded (MacDougall, 1977).

Simonson (1971) recorded ventilation during a step wise increase in work load until a work load was reached where the increase in ventilation became steeper. Prolonged performance was possible only at loads below this critical limit. The closer the critical limit was to the MAP the more advantageous it was when participating in endurance events. Some investigators (Costill, & Winrow, 1970; and Davies, 1969) felt that distance runners had the ability to 'cruise' at close to 80% of their MAP for extended periods of time.

Maximum Aerobic Capacity (MAC) vs. Maximum Aerobic Power (MAP)

Testing MAP has been used by researchers in the past and to the present day as the index for physical work capacity (Issekutz, Birkhead, & Rodahl, 1962; Parnat, Viru, & Nurmekivi, 1975; Shapiro, A., Shapiro, Y., & Magazanik, 1976; and Wilmore, 1969) and the level of fitness (Byrne-Quinn, Weil, et al, 1971; Cumming, 1967; Klissouras, 1973; and Shephard, Allen, et al, 1968).

Cumming (1967) and Davies (1969) expressed some doubt as to whether MAP was the best and only measure of fitness due to the discrepancy caused by diet and genetics. Davies (1969) felt that some individuals may be genetically endowed with optimum physical dimensions of the relevant organs which contributed to the capacity for exercise and a subsequent high MAP. Klissouras (1973) in a study using identical twins found that vigorous training did not contribute to physical fitness beyond a limit set by the genotype. It was concluded that when using MAP the genetic factor was the principal determinant of the variability in physical fitness, and chronic exercise affected the expression of the genetic potential, but only within fixed limits of heredity. While MAP was regarded as the best physiological criterion of endurance capacity, it did have certain limitations.

Williams, Wyndham, et al, (1967) investigated the dilemma of whether training increased the capacity for exercise by increasing the MAP, or whether it raised the level of oxygen consumption, relative to the individual's maximum, at which anaerobic metabolism occurred. It was shown that MAP and MAC increased 7% and 16% respectively with training. MAC had increased from 46% to 64% in the untrained individuals after a period of training. One individual increased from 38% to above 89% in 30 months of training (Londeree, 1977). Therefore, performance improved even after reaching an upper limit or ceiling for MAP by developing the ability to work at a higher percentage of the MAP (Wilmore, 1977). Costill and Winrow (1970) while studying two competitive marathon runners, discovered that the athlete with the lower MAP but greater fractional utilization of that value was consistently defeating his opponent. When the economy of running was similar in a group of runners, the individual with the highest MAC had a decided advantage (Mayhew, & Andrew, 1975).

Summary

A maximum aerobic power test which is time consuming, expensive, has genetic limitations and requires the person to produce a maximum effort may not be the best method for testing the level of training.

A maximum aerobic capacity test using the nonlinear increase in ventilation would enable an investigator to locate the anaerobic threshold and terminate the test without having the person produce a maximal exertion.

Chapter 3

METHODS AND PROCEDURES

Hypothesis

There will be a significant difference in the mean level of maximum aerobic capacity (MAC) for the untrained and trained groups of individuals, and MAC will be an equal if not better index of a person's level of training than MAP.

Subjects

Forty male subjects ranging in age from 19 to 42 years were classified according to their score on an activity point schedule. (Appendix A). The subjects who accumulated more than 50 points per week were classified in the Excellent category (Cooper, 1977).

Subjects were requested to refrain from participating in any strenuous exercise prior to the testing.

Research Design

The subjects were categorized according to the average number of aerobic points they accumulated per week. The level of training (trained, untrained) was the independent variable and the dependent variable was the subject's MAC.

Apparatus

Bicycle Ergometer - a Monark bicycle ergometer equipped with pedal toe clips and calibrated with kilogram weights was used for the testing.

Volumeter - a Parkinson Cowan Volumeter with a potentiometric attachment furnished a continuous graph of the ventilation on a strip chart recorder. Various volumes measured with the volumeter were checked against known volumes in the laboratory's Tissot tank. The volumes were corrected to Standard Temperature Pressure Dry (STPD).

Gas Analyzers - an Infra Red Gas Analyzer was used to measure the carbon dioxide content of the samples of expired air. The analyzer was calibrated prior to the testing using room air and a test gas with a known percentage of carbon dioxide.

A Taylor Servomex (type OA 272) oxygen analyzer was used to measure the oxygen content of the samples of expired air. The analyzer was calibrated prior to the testing using room air, and a test gas with a known percentage of oxygen.

Test Gases - the cylinder of test gas contained 10.91% oxygen, 4.0% carbon dioxide and the balance was nitrogen. The test gas was checked using the micro-Scholander apparatus.

Recorder - a Hewlet Packard 680 strip chart recorder was connected to a potentiometer on the volumeter.

E.C.G. - a Cambridge VS4 electrocardiogram monitored heart rate prior to and throughout the test session.

Measurement of MAC and MAP

Upon arriving at the laboratory the subjects were weighed on a medical scale (Healthometer) and had the electrocardiogram leads applied. Heart rate was monitored so the tester knew when to start collecting the expired air. The temperature and barometric pressure were recorded just prior to each test. The seat height on the bicycle ergometer was adjusted so that the subject's legs were slightly hyperextended when the pedal was in the down position. Even though the bicycle ergometer may have elicited a lower anaerobic threshold than the treadmill it was used for the testing due to the ease of habituation and the subjects' prior experience in exercising on this type of ergometer. The head gear was adjusted to hold the Rudolph Valve #2700 in place. The valve was connected to the inlet of the volumeter by a short piece of flexible plastic hose. As the subjects exercised, expired air flowed through the volumeter and into the collection balloons. A potentiometer attached to the volumeter allowed the tester to observe the subject's ventilation on a strip chart recorder while the test was in progress. The testing arrangement is shown in Figures 1 and 2.

Each subject pedalled the bicycle ergometer at 60 rpm and the first four minutes of pedalling was at zero resistance (Davis, Vodak, P., et al, 1976; and Wasserman, Whipp, et al, 1973). When the trained subjects approached a heart rate of 100 bpm and the untrained subjects approached a heart rate of 90 bpm, one minute samples of expired air were collected for analysis.

Numbered rubber stoppers were used to seal the balloons of expired air until after the test (approximately 20 min.). A sample from each balloon was analyzed for percentages of oxygen and carbon dioxide. The test was continuous and the work load increased 0.5 Kp* (25W) every minute commencing at the end of the fourth minute until the anaerobic threshold was reached. Once the examiner observed the subject pass his anaerobic threshold a modified Astrand MAP test was used.

Calculation of MAC and MAP

MAC was calculated by locating the anaerobic threshold using ventilation

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*Kp - Kilopond - a force of gravity acting on a kilogram weight. (kpm - kilopond metre per minute)

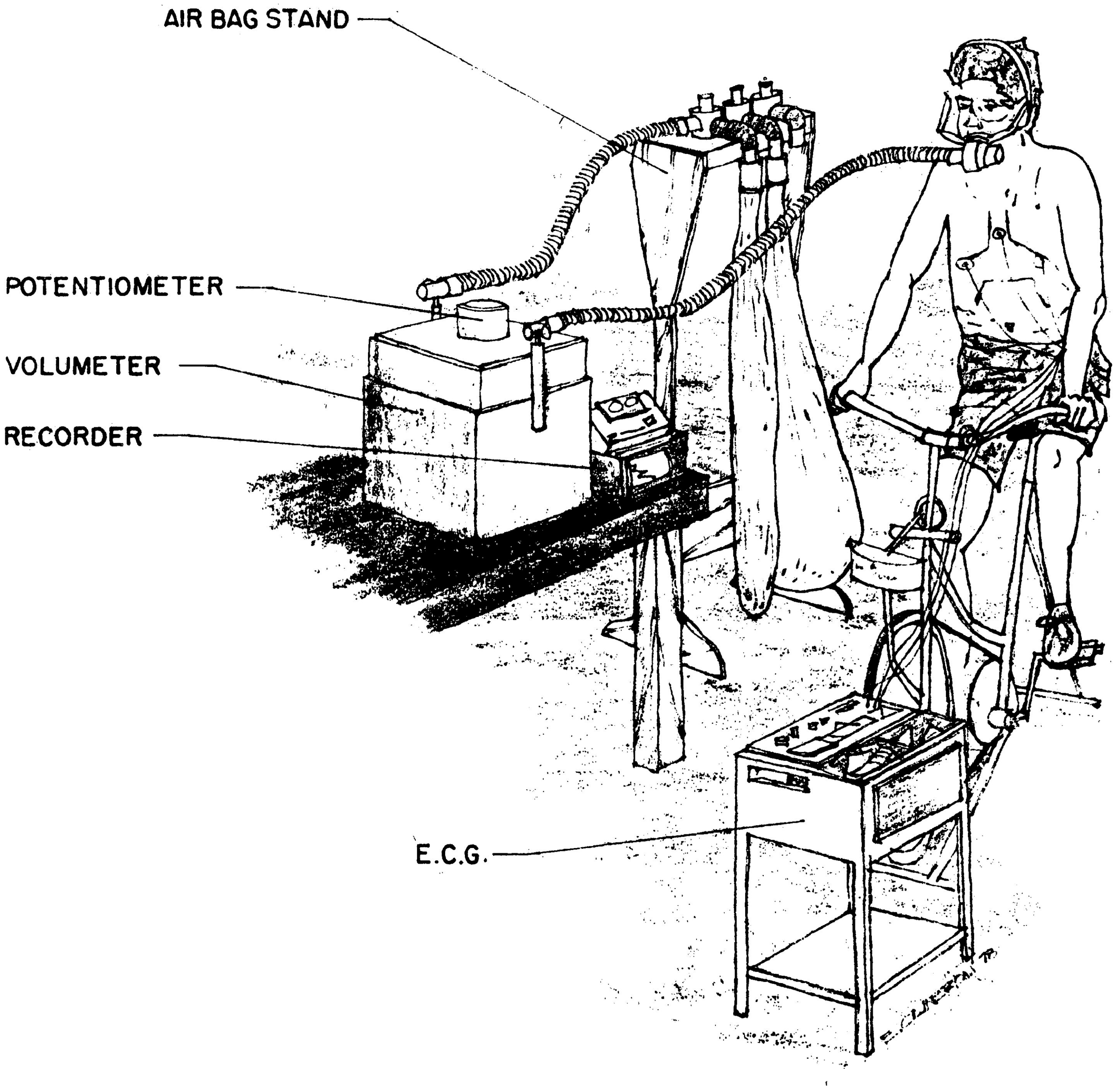

Figure 1. Volumeter and Recorder

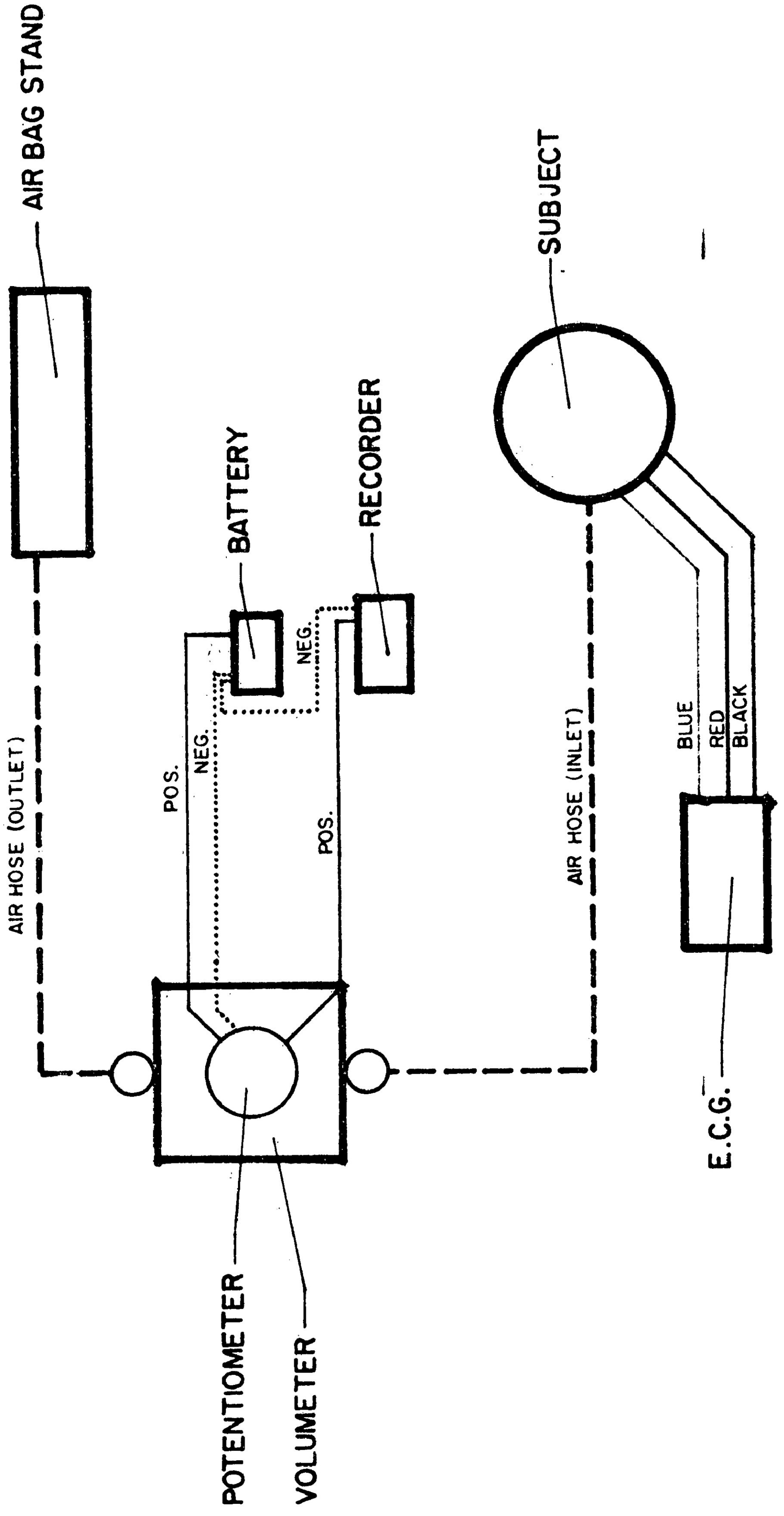

Figure 2. Testing Arrangement (top view)

(Bailey, 1975; Davis, Vodak, P., et al, 1976; MacDougall, 1977; and Wasserman, Whipp, et al, 1973). The ventilation was plotted against the respective work load. The line of best fit was extended through the subject's ventilation points from the lowest work load to intersect the line of best fit for the ventilation points extending from the highest work load. The point at which these lines intersected was the deviation in ventilation linearity and was considered the subject's MAC. MAC involved all the work that was done below the anaerobic threshold. The oxygen consumption at MAC was divided by the oxygen consumption at MAP and multiplied by 100. This represented the percentage of the maximum at which the subject was able to work aerobically.

The criterion that was used to indicate that MAP had been attained was a difference in oxygen consumption of less that 2 ml/kg/min with increasing work load (Shephard, Allen, et al, 1968).

Pilot Study

A pilot study was carried out to 1) eliminate any deficiencies in the testing procedure and 2) observe the independent and dependent variables.

Localized muscle fatigue in the upper thigh muscles was alleviated somewhat, by having the seat height adjusted so that there was a slight hyperextension of the knee when pedalling at the heavier work loads. Different lengths of time at each work load were tested to find out which elicited the truest anaerobic threshold (Wasserman, Whipp, et al, 1973).

Analysis of Data

Statistical significance was set at the .05 confidence level prior to the analysis of the data. The data was analyzed using Pearson

Product Moment Correlation and t-tests for significant differences. Test reliability was established by re-testing the subjects to locate their anaerobic threshold and determine their MAC.

Presentation of the Data

Graphs are presented to illustrate the difference in maximum aerobic capacities of the trained and untrained subjects. Individual data for the work load at MAC, the first work load above MAC and the work load at MAP are presented in tabular form within Appendix B and C.

Chapter 4

RESULTS

Sample Characteristics

Forty male subjects ranging in age from 19 to 42 years were assigned to one of two groups, either trained or untrained, depending upon the average number of aerobic points they earned per week. Two of the subjects in the trained group were professional hockey players and the rest were joggers. The joggers were running distances of 25 to 100 miles or more per week. Most of the untrained group were engaged in no systematic physical activity although a few individuals played tennis or golf once a week. The means and standard deviations for age, body weight, and average number of aerobic points per week are presented in Table 1.

MAC Test Results

The individual raw data for the work load at MAC and the first work load above MAC are shown in Appendix B. The means and standard deviations of the relevant variables for both the trained and untrained group for the work load at MAC are shown in Table 2. The highest MAC was attained by a trained subject (80.1%) and the lowest by an untrained subject (18.8%), which was a difference of 61.3%. The mean heart rate at MAC (HR MAC) for the trained group was significantly higher ($t(38) = -4.65$, $p < .001$) than the mean heart rate at MAC for the untrained group. The subjects of the trained group were capable of working at a significantly higher ($t(38) = -6.76$, $p < .001$) percentage of their

Table 1

Means and Standard Deviations for Age, Body Weight and Aerobic Points

	Age (yrs)	Body Weight (Kg)	Aerobic Points (per / week)
Trained (N = 20)	29.00 ±6.86	74.86 ±9.84	272.05 ±133.46
Untrained (N = 20)	30.45 ±6.19	79.69 ±9.77	24.10 ± 15.14

Table 2

Means and Standard Deviations of the Relevant Variables for the Work Load at MAC

	W. L. (Kpm / Min)	MAC (%MAP)	$\dot{V}E$ (L / Min)	$\dot{V}O_2$ (L / Min)	H. R. (bpm)	PO MAP HR (%)
Trained (N = 20)	1260.00 ±210.56	60.46 ±8.66	50.75 ±8.89	2.64 ±.38	140.60 ±12.71	80.12 ±6.05
Untrained (N = 20)	711.00 ±214.38	35.98 ±10.03	27.27 ±7.01	1.37 ±.53	122.65 ±11.71	67.27 ±5.97

maximum heart rate (PO MAP HR) at MAC than the subjects of the untrained group. The means and standard deviations for the percent of maximum heart rate at MAC, for both groups, are reported in Table 2.

The mean work load at MAC for the trained group was significantly higher ($t(38) = -8.17$, $p < .001$) than that achieved by the untrained group. The oxygen consumption, for those respective groups, for the work load at MAC was 2.64 ± .38 L/min. and 1.37 ± .53 L/min.

Ventilation at MAC was significantly greater ($t(38) = -9.27$, $p < .001$) for the trained group. Each subject's ventilation in relation to the two work loads below and the two work loads above MAC is presented in Appendix D and E.

MAP Test Results

The individual raw data for the work load at MAP is shown in Appendix C. Of the 20 trained subjects 17 exhibited a levelling off or a slight decrease in oxygen consumption with increasing work load, while 16 of the 20 untrained subjects exhibited this same pattern which was used as a criterion for obtaining MAP values (Astrand, 1956). The 7 subjects who did not demonstrate this pattern were unable to pedal the bicycle ergometer at a higher work load due to localized fatigue. The mean absolute and relative MAP values, along with other relevant variables for the work load at MAP are presented in Table 3. The highest MAP value reached was 73.1 ML/Kg/Min and the lowest was 34.0 ML/Kg/Min.

The mean work load at MAP was significantly greater ($t(38) = -4.38$, $p < .001$) for the trained group than the untrained group.

Correlations

A correlation matrix on the five dependent variables for this study is presented in Table 4.

Table 3

Means and Standard Deviations of the Relevant Variables from the MAP Test

	W.L. (Kpm/Min)	$\dot{V}O_2$ (L/Min)	$\dot{V}O_2$ (ML/Kg/Min)	H.R. (bpm)
Trained	2097.00	4.37	58.93	175.30
(N = 20)	±235.60	±.43	±6.26	±6.28
Untrained	1728.00	3.71	46.75	182.40
(N = 20)	±294.33	±.63	±6.97	±9.83

Table 4

Correlations among the Five Dependent Variables

	Points	MAC	MAP	Age	Weight
Points	---				
MAC	.6901[d]	---			
MAP	.7515[d]	.7426[d]	---		
Age	-.1970	-.0715	-.2921[a]	---	
Weight	-.3544[b]	-.3091[b]	-.4466[c]	.1516	---

[a] $p < .10$

[b] $p < .05$

[c] $p < .01$

[d] $p < .001$

Maximum aerobic capacity correlated significantly ($p < .001$) with maximum aerobic power, and the state of training (average number of aerobic points earned per week). MAC and age were not as strongly correlated as MAP and age.

Reliability of MAC Test

The reliability of the MAC test was calculated by the test-retest method. The Pearson product-moment correlation was used to obtain reliability coefficients. A correlation of .80 ($p < .001$) was obtained for MAC when 30 of the 40 subjects were retested. A second correlation of .89 ($p < .001$) was obtained for MAC when the subjects that had changed their training regime by more than 50 points per week were eliminated. Six trained subjects decreased their training following a ten mile road race and 2 untrained subjects started to train.

In the present study the mean level of maximum aerobic capacity was significantly higher ($t(38) = -8.30$, $p, < .001$) for the trained group when compared to the untrained group.

Chapter 5

DISCUSSION

Subjects who were relatively sedentary or highly trained were asked to volunteer for testing to ensure that there was a difference in the level of training between the two groups. There was no significant difference in age ($t(38) = 0.70$, $p < .487$) or body weight ($t(38) = 1.56$, $p < .128$) for the two groups, however, there was a significant difference in the average number of aerobic points ($t(38) = -8.26$, $p < .001$) they earned per week (Table 5). The subjects of this study were slightly older and heavier than the subjects used by Bailey (1975) and Davis, Vodak, P., et al (1976). Bailey (1975) used 26 subjects of varying levels of fitness and Davis, Vodak, P., et al (1976) used 30 subjects that had not undergone any endurance training for at least 4 months prior to testing.

MAC Test

The findings of this study showed a significant difference ($t(38) = -8.30$, $p < .001$) for the mean level of MAC between the trained and untrained groups of individuals. The mean level of MAC for the trained group was 60.46 ±8.66% and 35.88 ±10.03% for the untrained group. The MAC values for the present study were lower than those reported in other investigations (Ekblom, Astrand, et al, 1968; and Nagle, Robinhold, et al, 1970). The most trained subject of this study recorded a MAC of 80.1% which was comparable to findings by Costill (1970) and MacDougall (1977) for highly trained endurance athletes.

Table 5

T - tests for Independent Samples on Training Groups

Variable	Group	N	Mean	Standard Deviation	t - Value	Degrees of Freedom	2 - Tail Probability
Points	T	20	272.06	133.46			
	UT	20	24.10	15.14	-8.26	38	0.000
MAC	T	20	60.46	8.66			
	UT	20	35.88	10.03	-8.30	38	0.000
MAP	T	20	58.92	6.26			
	UT	20	46.75	6.97	-5.81	38	0.000
Age	T	20	29.00	6.86			
	UT	20	30.45	6.19	0.70	38	0.487
Weight	T	20	74.86	9.84			
	UT	20	79.70	9.77	1.56	38	0.128
HR MAC	T	20	140.60	12.71			
	UT	20	122.65	11.71	-4.65	38	0.000
PO MAP HR	T	20	80.12	6.05			
	UT	20	67.27	5.97	-6.76	38	0.000
W. L. MAC	T	20	1260.00	210.56			
	UT	20	711.00	214.38	-8.17	38	0.000
W. L. MAP	T	20	2097.00	235.60			
	UT	20	1728.00	294.33	-4.38	38	0.000
$\dot{V}E$ MAC	T	20	50.75	8.89			
	UT	20	27.27	7.01	-9.27	38	0.000

$p < .05$ Requires a t - value of ± 2.042 or greater

The heart rate at MAC and the percent of maximum heart rate were significantly higher for the trained group than the untrained group (Table 5). Sampling technique may have caused this difference because the subjects of the trained group earned anywhere in excess of 50 points per week, while the subjects of the untrained group were limited to 50 points or less per week. Bailey (1975) reported that the average heart rate at MAC, when using ventilation to indicate MAC, was 129.3 ± 18.1 bpm. The findings of this study showed that the mean heart rate at MAC for the trained group was 140.60 ± 12.71 bpm and 122.65 ± 11.71 bpm for the untrained group. The trained group was working at a mean of 80.12 ± 6.05% of their maximum heart rate when at MAC. The untrained group however, was working at a significantly lower percentage (67.27 ± 5.97) of their maximum heart rate when at MAC, but this value was comparable to the average 70.3 ± 10.4% reported by Bailey (1975).

The mean work load achieved at MAC by the trained group was 1260.00 ± 210.56 Kpm/min and for the untrained group was 711.00 ± 214.38 Kpm/min, compared with 810.8 ± 290.7 Kpm/min stated by Bailey (1975) and 1200.00 ± 201.7 Kpm/min found by Davis, Vodak, P., et al (1976).

The oxygen consumption at MAC for the trained group (2.64 ± .38 L/min) was greater than the findings of Bailey (1975) when using ventilation to locate MAC and Davis, Vodak, P., et al (1976) when studying leg cycling, however, the oxygen consumption for the untrained group at MAC was less than that reported in both of the studies. Williams, Wyndham, et al (1967) found the oxygen consumption in the trained and untrained state to be 2.4 L/min and 1.8 L/min respectively.

Bailey (1975) reported similar values to those of the trained group for ventilation at MAC. These values were twice as great as those recorded for the untrained group.

MAP Test

Even though most of the subjects of the trained group were avid runners the MAP testing was done on the bicycle ergometer due to the ease of habituation and the fact that all of the subjects had some form of prior experience in riding a bicycle. The investigator felt that testing the MAP of the untrained subjects was easier and safer on the bicycle ergometer than on the treadmill. In the present study the bicycle ergometer was equipped with pedal toe clips which enabled the subjects to pedal more efficiently at the higher work loads. It had been demonstrated that a bicycle ergometer equipped with toe clips produced comparable results to those attained on a treadmill when testing MAP (LaVoie, 1978). Hermansen (1973) reported that pulmonary ventilation was not significantly different for the two modes of exercise. Davis, Vodak, P., et al (1976) reported no significant difference between anaerobic threshold values attained while pedalling the bicycle ergometer or treadmill walking.

The trained group recorded a greater work load, absolute and relative oxygen consumption, and a lower maximum heart rate for the work load at MAP than the untrained group.

Correlations

MAC had a significant correlation of .69 ($p < .001$) with the level of training, and a correlation of -.31 ($p < .05$) with body weight. The subjects who accumulated more points had a subsequent high MAC and tended to weigh less than the subjects who accumulated fewer points. Body weight and MAC were not as strongly correlated as MAP and body weight. Correlations are reported in Table 4.

In the present study MAC was found to correlate .74 ($p < .001$) with

MAP. Bailey (1975) stated that MAC, when measured using the nonlinear increase in ventilation had a correlation of .82 with MAP. Other findings showed that MAP correlated -.29 ($p < .10$) with age while MAC correlated -.07 ($p > .10$) with age. A t-test for significance of the difference between two correlation coefficients for correlated samples (Ferguson, 1976) showed that the correlation coefficient for MAP and age was significantly greater ($t(37) = -3.78$, $p < .01$) than the correlation coefficient for MAC and age. Since MAC was less related to age than MAP, and MAC had a significant correlation with MAP, it was concluded that MAC was no less efficient than MAP when assessing a person's state of training.

It has been shown that the MAC test was a simple, indirect and relatively inexpensive technique used for evaluating a person's state of training. This test was beneficial in that it did not require blood samples and the subject did not have to produce a maximum exertion. The departure from linearity of ventilation rate was proven to be as good a predictor of the anaerobic threshold, as the increase in lactic acid above the resting level, when measuring MAC (Bailey, 1975; and Davis, Vodak, P., et al, 1976).

Chapter 6

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

The objective of the present investigation was to devise a simple method of measuring MAC using the nonlinear increase in ventilation rate during an incremental work test, and to show that MAC was equivalent to MAP when evaluating a person's level of training.

T-tests for independent samples were used to analyze the data for the trained and untrained group. The groups were determined by the average number of aerobic points the subjects earned per week. Pearson product-moment correlations were also used to determine the correlation of five relevant variables with MAC.

Forty male subjects (19 to 42 years) participated in the study. Twenty subjects were trained (more than 50 points per week) while the other 20 subjects were untrained (50 points or less per week). An attempt was made to use subjects that were either highly trained or relatively sedentary. It was necessary to use volunteers in the study due to the stress involved in MAP testing.

The MAC and the MAP test were measured on a Monark bicycle ergometer equipped with pedal toe clips. MAP was measured using the "leveling off" criterion of Astrand (1956) or when the subject was unable to pedal any further. MAC was calculated by monitoring ventilation rate during a continuous incremental work test to the point at which the ventilation became nonlinear.

Each subject pedalled the bicycle ergometer at 60 RPM for the first four minutes at '0' resistance and then the work load was incremented by

0.5 Kp. at the end of each minute. Samples of expired air from the balloon at each work load were analyzed for carbon dioxide and oxygen content to determine what the oxygen consumption was for each of the work loads. Volumes of expired air for each work load were recorded on a strip chart recorder. Ventilation responses from the MAC test were plotted against the respective work load for each subject. MAC was determined by dividing the subject's oxygen consumption at the work load where ventilation became nonlinear, by the subject's oxygen consumption for the work load at MAP.

Data was analyzed using Pearson Product Moment Correlation and t-tests for significant differences. Graphs were constructed to illustrate the difference in maximum aerobic capacities of the trained and untrained subjects.

Conclusions

In terms of the subjects studied in this investigation:

1. There was a significantly greater mean level of MAC for the trained group when compared to the untrained group.
2. There was no evidence that the MAC test was any less efficient than the MAP test for separating out levels of training.
3. MAP and age had a more significant ($p < .01$) correlation than MAC and age. Since MAC was less related to age it might be a better test for evaluating a person's state of training.
4. The trained subjects had a higher mean heart rate at MAC and were capable of working at a higher percentage of their maximum heart rate at this point.

The reliability of using ventilation for measuring MAC was established at .89 using the test-retest method, providing the subjects maintained the same training regime.

Recommendations

A study could be carried out on a group of subjects to determine how much training is necessary to increase MAC, as well as, how much detraining is necessary before MAC begins to decrease.

A comparative study could be done on a group of subjects to determine the extent to which the level of MAC and MAP are affected by varying periods of training and/or detraining.

A procedure could be developed for predicting MAP using the work load at MAC, the percentage of MAP heart rate when at MAC, age and body weight.

A better technique could be developed to measure MAC without requiring the subject to do a MAP test.

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APPENDICES

APPENDIX A

DATA COLLECTION SHEETS

ACTIVITY SCHEDULE

Subject: ______________________________

FREQUENCY PER WEEK

		1	2	3	4	5	6	7
WALKING	1 to 2 miles							
	2 miles or more							

JOGGING

			1	2	3	4	5	6	7
1 mile	☐	over 8 mins.							
	☐	under 8 mins.							
	☐	under 6 mins.							
1 to 2 miles	☐	under 12 mins.							
	☐	under 16 mins.							
3 to 5 miles	☐	8 mins. or more/mile							
	☐	7 mins./mile							
	☐	6 mins./mile							
	☐	less than 6min/mile							
6 to 10 miles	☐	9 mins or more/mile							
	☐	8 mins/mile							
	☐	7 mins/mile							
	☐	less than 6min/mile							
10 miles or more									

		1	2	3	4	5	6	7
CYCLING	1 to 5 miles							
	5 to 10 miles							
	10 miles or more							
SWIMMING	200 to 500 yards							
	500 to 1000 yards							
	1000 yards or more							

		1	2	3	4	5	6	7
HANDBALL/SQUASH BASKETBALL/BASEBALL	Less than 30 mins.							
	30 to 50 mins.							
(continuous activity time excluding breaks)	50 to 70 mins.							
	70 to 90 mins.							
	90 mins. or more							

.football									
GOLF	- 9 holes - 18 holes								
Rowing	(20 strokes) 6 mins.								
	18 mins.								
	36 mins.								
TENNIS	1 set								
	2 set								
	3 set								
WRESTLING	5 min.								
	10 min.								
	15 min.								

OTHER (Specify)							

Date:

Subject:

Temp.
Barr. Press.
C.F.

Age

Wt.

Pre Test Hr.

WL. # 1
2
3
4
5
6
7
8
9
10
11
12
13
14

Gas Analysis

	CO_2	O_2	N_2	V_E
Bag #				

WL. # 1 VO_2 VCO_2 RQ VO_{2MAX} MAC

APPENDIX B

RAW DATA FROM THE WORK LOAD AT MAC AND THE FIRST WORK LOAD ABOVE MAC FOR THE TRAINED AND UNTRAINED GROUPS

Table 6

1. Raw Data for the Work Load at MAC

Subject (Trained)	Age (yrs)	Wt. (kg)	Percentage			$\dot{V}E$ (L/min) STPD	W.L. (kpm/min)	$\dot{V}O_2$ (L/min)	$\dot{V}O_2$ (ml/ kg/min)	MAC (% MAP)	H.R. MAC	H.R. MAP	% of H.R. MAP	R.Q.	% of $\dot{V}E$ MAP
			O_2	CO_2	N_2										
P.A.	39	70.7	15.75	4.18	80.07	39.6	900	2.16	30.6	52.8	127	170	74.7	.75	32.7
R.B.	24	62.1	16.48	4.4	79.12	57.9	1260	2.57	41.4	66.7	155	170	91.1	.98	50.6
N.C.	23	66.6	15.25	5.4	79.35	53.5	1440	3.08	46.2	71.5	158	184	85.8	.93	47.9
J.E.	36	72.9	16.15	4.0	79.85	47.5	1080	2.37	32.5	57.5	125	164	76.2	.79	38.2
E.F.	26	80.5	16.0	4.7.	79.3	51.3	1440	2.57	32.0	58.4	132	167	79.0	.93	35.9
B.F.	35	78.0	15.9	4.5	79.6	46.6	1080	2.41	30.9	54.1	132	180	73.3	.86	39.9
P.G.	25	81.8	16.75	3.1	80.15	54.9	1080	2.44	29.8	50.1	132	173	76.3	.69	38.4
J.G.	28	67.7	15.16	5.1	79.74	43.1	1260	2.56	37.8	55.2	143	180	79.4	.85	40.2
K.G.	21	68.8	15.5	4.7	79.8	50.0	1260	2.81	40.8	55.8	155	187	82.8	.83	40.9
S.H.	27	71.0	17.2	3.01	79.79	70.9	1260	2.79	39.3	60.3	136	173	78.6	.75	56.9
M.H.	21	89.0	15.4	4.8	79.8	46.4	1260	2.65	29.7	59.1	125	176	71.0	.83	42.3
N.J.	40	68.2	15.6	5.0	79.4	43.8	1260	2.35	34.5	63.6	134	164	81.7	.92	45.4
T.J.	21	91.5	15.8	4.1	80.1	47.5	1080	2.56	28.0	53.3	141	180	78.3	.75	39.1
W.L.	41	72.0	15.1	4.78	80.12	33.1	1080	2.04	28.3	53.4	138	176	78.4	.76	35.4
N.L.	35	82.7	15.6	5.0	79.4	53.3	1260	2.88	34.8	68.8	136	176	77.2	.92	35.7
W.M.	25	88.6	15.3	5.19	79.51	58.9	1800	3.39	38.5	65.2	150	173	86.7	.89	44.6
B.M.	25	59.5	15.8	4.45	79.75	42.8	1080	2.27	38.1	57.7	148	180	82.2	.83	39.4
B.N.	23	71.4	15.8	5.1	79.1	66.9	1620	3.43	48.0	77.0	155	180	86.1	.98	56.6
B.R.	37	63.8	15.75	4.2	80.05	55.5	1440	3.02	47.3	80.1	167	180	92.7	.76	45.8
C.T.	27	90.5	16.24	2.79	78.97	51.5	1260	2.41	26.6	51.4	123	173	71.0	1.01	40.0

Table 6

2. Raw Data for First Work Load Above MAC

Subject (Trained)	Age (yrs)	Wt. (kg)	Percentage O_2	CO_2	N_2	$\dot{V}E$ (L/min) STPD	W.L. (kpm/min)	$\dot{V}O_2$ (L/min)	$\dot{V}O_2$ (ml/ kg/min)	MAC (% MAP)	H.R. MAC	H.R. MAP	% of H.R. MAP	R.Q.	% of $\dot{V}E$ MAP
P.A.	39	70.7	15.75	4.41	79.84	50.2	1080	2.71	38.3	66.3	143	170	84.1	.81	41.4
R.B.	24	62.1	16.65	4.38	78.97	79.8	1440	3.40	54.7	88.3	167	170	98.2	1.02	69.6
N.C.	23	66.6	15.5	5.4	79.1	66.7	1620	3.63	54.5	84.2	167	184	90.7	.99	59.7
J.E.	36	72.9	16.4	4.0	79.6	60.9	1260	2.85	39.1	69.1	136	164	82.9	.84	48.9
E.F.	26	80.5	16.25	4.6	79,15	62.9	1440	2.94	36.5	66.8	141	167	84.4	.95	44.0
B.F.	35	78.0	16.05	4.62	79.33	56.8	1260	2.82	36.1	63.3	148	180	82.2	.92	48.5
P.G.	25	81.8	16.35	3.7	79.95	60.0	1260	2.89	35.3	59.3	145	173	83.8	.76	41.9
J.G.	28	67.7	15.2	5.24	79.56	53.6	1440	3.15	46.5	68.0	155	180	86.1	.88	49.9
K.G.	21	68.8	15.55	4.77	79.68	60.7	1440	3.37	49.0	66.9	164	187	87.7	.85	49.7
G.H.	27	71.0	17.05	3.22	79.73	77.1	1440	2.93	41.3	60.3	143	173	82.6	.83	61.9
M.H.	21	89.0	15.49	5.0	79.51	57.5	1440	3.19	35.8	71.2	134	176	76.1	.89	54.8
N.J.	40	68.2	15.75	5.1	79.15	55.6	1440	2.90	42.5	78.5	138	164	84.1	.97	57.6
T.J.	21	91.5	16.0	4.16	79.84	58.7	1260	3.02	33.0	6.29	153	180	85.0	.80	48.3
W.L.	41	72.0	15.27	4.9	79.83	46.9	1260	2.76	38.3	72.2	143	176	81.2	.82	50.1
N.L.	35	82.7	16.25	4.7	79.05	72.4	1440	3.39	40.9	81.1	148	176	84.0	.99	48.7
W.M.	25	88.6	15.3	5.4	79.3	70.5	1980	4.02	45.7	77.3	161	173	93.1	.94	53.4
B.M.	25	59.5	16.0	4.6	79.4	54.1	1260	2.72	45.7	69.2	158	180	87.7	.90	49.7
B.N.	24	71.4	16.0	5.19	78.81	81.4	1800	3.97	55.6	89.2	167	180	92.7	1.05	68.9
B.R.	37	63.8	16.0	4.6	79.4	68.8	1620	3.46	54.2	91.7	173	180	96.1	.90	56.7
C.T.	27	90.5	16.2	4.8	79.0	59.9	1440	2.83	31.3	60.4	134	173	77.4	1.01	46.4

Table 7

1. Raw Data for the Work Load at MAC

Subject (Untrained)	Age (yrs)	Wt. (kg)	Percentage O_2	CO_2	N_2	$\dot{V}E$ (L/min) STPD	W.L. (kpm/min)	$\dot{V}O_2$ (L/min)	$\dot{V}O_2$ (ml/ kg/min)	MAC (% MAP)	H.R. MAC	H.R. MAP	% of H.R. MAP	R.Q.	% of $\dot{V}E$ MAP
B.A.	28	90.0	17.27	3.1	79.63	16.1	360	.61	6.7	19.9	132	195	67.6	.80	16.1
T.A.	19	72.0	15.1	4.81	80.09	33.8	900	2.05	28.5	49.2	123	195	63.0	.78	33.4
J.B.	24	68.0	16.8	3.6	79.6	25.5	540	1.09	16.0	36.5	148	187	79.1	.83	26.7
E.C.	25	80.0	16.0	3.82	80.18	26.4	720	1.38	17.3	35.2	130	187	69.5	.72	20.9
D.C.	30	73.2	16.98	3.21	79.81	15.8	360	.66	9.0	21.9	111	187	60.3	.75	21.4
F.D.	35	76.0	15.57	4.45	79.98	31.0	900	2.00	26.3	52.0	120	173	69.4	.79	37.1
D.H.	38	87.0	16.25	3.82	79.93	26.6	900	1.31	15.0	34.3	114	164	69.5	.77	24.9
M.H.	25	79.0	15.75	4.4	79.85	36.4	900	1.97	24.9	46.6	138	184	75.0	.80	32.2
R.H.	39	98.0	16.72	3.7	79.58	21.2	540	.91	9.3	26.3	110	180	61.1	.85	22.8
J.H.	26	78.5	17.1	2.8	80.1	15.2	360	.63	8.0	18.8	111	195	65.9	.66	13.0
H.K.	25	71.5	16.0	4.4	79.6	34.8	900	1.76	24.6	45.3	136	180	75.5	.86	31.5
R.M.	41	94.5	15.2	4.1	80.7	36.0	900	2.23	23.5	46.3	107	158	67.7	.65	34.1
B.M.	35	84.8	15.48	4.4	80.12	33.0	900	1.91	22.5	43.6	114	180	63.3	.75	26.3
J.S.	23	69.0	16.1	3.9	80.0	21.7	720	1.11	16.1	32.9	127	184	69.0	.75	20.9
G.S.	39	85.9	15.51	4.1	80.39	29.3	720	1.69	19.7	43.8	123	180	68.3	.71	27.0
W.S.	29	86.5	16.5	3.7	79.8	28.6	720	1.32	15.2	38.1	114	173	65.8	.79	36.3
S.S.	35	77.0	15.9	4.35	79.75	33.6	900	1.75	22.7	41.0	129	191	67.5	.82	27.8
L.S.	30	77.0	15.98	3.41	80.61	22.4	720	1.20	15.6	29.9	105	187	56.1	.63	18.1
G.V.	30	88.0	17.2	2.78	80.02	30.2	900	1.20	13.6	27.3	132	180	73.3	.69	22.7
R.Y.	33	58.0	16.6	3.5	79.9	13.5	360	.60	10.3	28.7	129	191	67.5	.78	29.2

Table 7

2. Raw Data for the First Work Load Above MAC

Subject (Untrained)	Age (yrs)	Wt. (kg)	Percentage			$\dot{V}E$ (L/min) STPD	W.L. (kpm/min)	$\dot{V}O_2$ (L/min)	$\dot{V}O_2$ (ml/kg/min)	MAC (% MAP)	H.R. MAC	H.R. MAP	% of H.R. MAP	R.Q.	% of $\dot{V}E$ MAP
			O_2	CO_2	N_2										
B.A.	28	90.0	16.95	3.3	79.75	22.2	540	.92	10.2	30.0	130	195	66.6	.79	22.2
T.A.	19	72.0	14.75	5.3	79.95	42.0	1080	2.70	37.5	64.9	136	195	69.7	.81	41.5
J.B.	24	68.0	16.54	4.0	79.46	32.9	720	1.48	21.7	49.6	167	187	89.3	.88	34.4
E.C.	25	80.0	15.75	4.39	78.86	39.4	900	2.02	25.3	51.0	145	187	77.5	.85	31.2
D.C.	30	73.2	16.35	3.5	80.15	21.1	540	1.03	14.1	34.2	118	184	64.1	.70	28.5
F.D.	35	76.0	15.6	4.58	79.82	35.8	1080	2.40	31.6	62.5	129	173	74.6	.82	42.8
D.H.	38	87.0	15.6	4.6	78.8	38.7	1080	2.04	23.4	53.5	129	164	78.6	.86	36.2
M.H.	25	79.0	15.9	4.6	79.5	48.5	1080	2,50	31.6	59.0	148	184	80.4	.88	42.9
R.H.	39	98.0	15.9	4.1	80.0	28.4	720	1.49	15.2	43.0	115	180	63.8	.77	30.5
J.H.	26	78.5	16.3	3.42	80.28	28.1	540	1.28	16.3	38.2	125	195	64.1	.75	23.9
H.K.	25	71.5	16.0	4.6	79.4	48.3	1080	2.43	34.0	62.6	150	180	83.3	.90	43.7
R.M.	41	94.5	15.0	4.59	80.41	43.7	1080	2.76	29.2	57.3	114	158	72.1	.72	41.3
B.M.	35	84.8	15.23	4.78	79.99	39.9	1080	2.38	28.1	54.3	125	180	69.4	.79	31.8
J.S.	23	69.0	15.53	4.2	80.27	29.5	900	1.89	27.4	56.0	143	184	77.7	.65	28.3
G.S.	39	85.9	15.4	4.4	80.2	37.6	900	2.20	25.6	57.1	132	180	73.3	.74	34.6
W.S.	29	86.5	16.0	4.2	79.8	38.4	900	1.97	22.8	56.9	125	173	72.2	.81	48.7
S.S.	35	77.0	15.26	5.02	79,72	40.2	1080	2.34	30.0	55.0	155	191	81.1	.85	33.2
L.S.	30	77.0	15.7	3.62	80.68	30.4	900	1.71	22.2	42.6	122	187	65.2	.64	24.6
G.V.	30	88.0	16.6	3.22	80.18	37.6	1080	1.75	19.9	39.9	141	180	78.3	.68	28.2
R.Y.	33	58.0	15.98	3.85	80.17	20.0	540	1.05	18.1	50.2	148	191	77.5	.73	43.2

APPENDIX C

RAW DATA FROM THE WORK LOAD AT MAP FOR THE TRAINED AND UNTRAINED GROUPS

Table 8

Raw Data for Work Load at MAP

Subject (Trained)	Age (yrs)	Wt. (kg)	Percentage			$\dot{V}E$ (L/min) STPD	W.L. (kmp/min)	$\dot{V}O2$ (L/min)	$\dot{V}CO_2$ (L/min)	MAP (ml/kg/min)	H.R. (MAP)	R.Q.	Aerobic Points (per week)
			O_2	CO_2	N_2								
P.A.	39	70.7	17.55	3.38	79.07	121.0	1980	4.09	4.05	57.9	170	.99	203
R.B.	24	62.1	17.5	3.8	78.7	114.5	1800	3.85	4.32	62.0	170	1.12	228
N.C.	23	66.6	17.0	4.2	78.8	111.6	1980	4.31	4.65	64.7	184	1.07	369
J.E.	36	72.9	17.6	3.4	79.0	124.5	1980	4.12	4.20	56.5	164	1.01	174
E.F.	26	80.5	17.7	3.8	78.5	142.7	2340	4.40	5.38	55.0	167	1.22	338
B.F.	35	78.0	17.0	4.45	78.55	116.9	1980	4.45	5.17	57.0	180	1.16	214
P.G.	25	81.8	17.49	3.6	78.91	142.9	1980	4.87	5.10	59.5	173	1.04	234
J.G.	28	67.7	16.48	5.0	78.52	107.3	1980	4.63	5.33	68.4	180	1.15	259
K.G.	21	68.8	16.76	4.42	78.82	122.1	2520	5.03	5.36	73.1	187	1.06	609
G.H.	27	71.0	17.25	3.6	79.15	124.4	2160	4.62	4.44	65.1	173	.96	609
M.H.	21	89.0	16.6	4.58	78.92	104.8	2160	4.48	4.76	50.3	176	1.06	161
N.J.	40	68.2	17.0	4.42	78.58	96.4	1800	3.69	4.23	54.1	164	1.14	229
T.J.	21	91.5	17.0	3.9	79.1	121.5	2160	4.80	4.70	52.4	180	.97	161
W.L.	41	72.0	16.75	4.58	78.67	93.5	1800	3.82	4.26	53.1	176	1.11	173.5
N.L.	35	82.7	17.95	3.65	78.4	148.6	2160	4.18	5.38	51.0	176	1.28	332.2
W.M.	25	88.6	16.85	4.65	78.5	132.0	2520	5.20	6.10	59.0	173	1.17	177.5
B.M.	25	59.5	17.2	4.18	78.62	108.7	1800	3.93	4.51	66.0	180	1.14	309
B.N.	24	71.4	17.0	4.58	78.42	118.1	2160	4.45	5.37	62.3	180	1.20	171
B.R.	37	63.8	17.75	3.5	78.75	121.2	2160	3.77	4.21	59.1	180	1.11	330
C.T.	27	90.5	17.1	4.58	78.32	128.9	2520	4.68	5.87	52.0	173	1.25	160

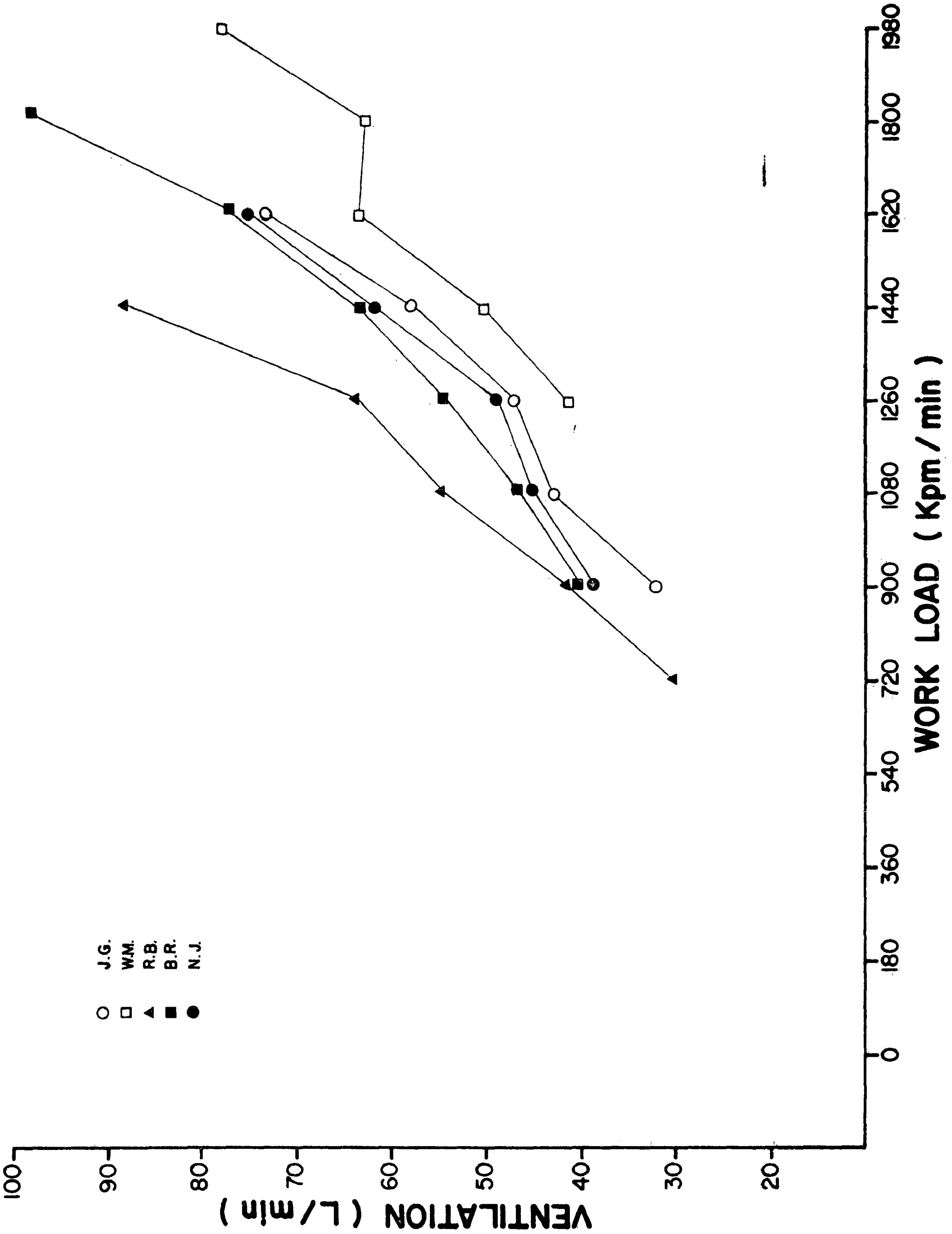
Table 9

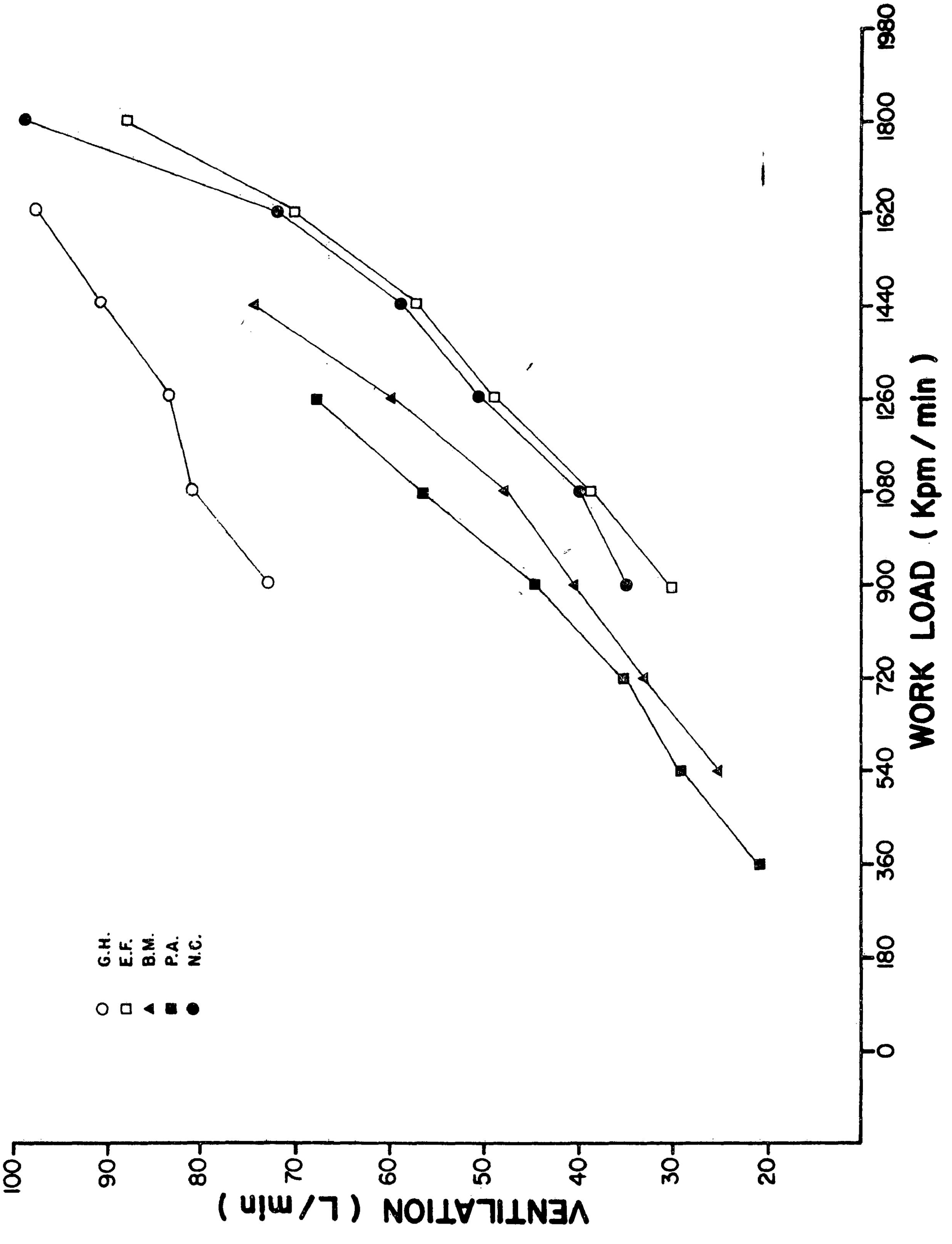
Raw Data for the Work Load at MAP

Subject (Untrained)	Age (yrs)	Wt. (kg)	Percentage			$\dot{V}E$ (L/min) STPD	W.L. (kmp/min)	$\dot{V}O_2$ (L/min)	$\dot{V}CO_2$ (L/min)	MAP (ml/kg/min)	H.R. (MAP)	R.Q.	Aerobic Points (per week)
			O_2	CO_2	N_2								
B.A.	28	90.0	17.8	3.38	78.82	99.7	1440	3.06	3.34	34.0	195	1.09	5
T.A.	19	72.0	16.73	4.58	78.69	101.2	1980	4.16	4.60	57.7	195	1.10	46.5
J.B.	24	68.0	17.7	3.7	78.6	95.6	1440	2.98	3.51	43.8	187	1.17	40.5
E.C.	25	80.0	17.75	3.5	78.75	126.2	1800	3.91	4.38	48.9	187	1.12	38.0
D.C.	30	73.2	16.8	4.4	78.8	74.0	1440	3.01	3.23	41.1	184	1.07	5
F.D.	35	76.0	16.3	4.78	78.92	83.5	1800	3.84	3.97	50.5	173	1.03	45
D.H.	38	87.0	17.26	4.1	78.64	106.9	1800	3.81	4.35	43.8	164	1.14	16
M.H.	25	79.0	17.1	4.2	78.7	113.0	1800	4.22	4.71	53.4	184	1.11	36
R.H.	39	98.0	17.05	4.5	78.45	92.9	1800	3.46	4.16	35.3	180	1.20	16
J.H.	26	78.5	18.0	3.2	78.8	117.3	1440	3.35	3.72	42.7	195	1.12	5
H.K.	25	71.5	17.4	3.6	79.0	110.5	1800	3.88	3.90	54.3	180	1.01	24
R.M.	41	94.5	16.45	4.2	79.35	105.6	1980	4.81	4.40	51.0	158	.92	31.5
B.M.	35	84.8	17.3	4.19	78.51	125.4	2160	4.38	5.22	51.7	180	1.19	5
J.S.	23	69.0	17.52	4.02	78.46	103.9	1800	3.37	4.14	48.8	184	1.22	27
G.S.	39	85.9	17.3	3.98	78.72	108.5	1800	3.85	4.28	44.8	180	1.11	5
W.S.	29	86.5	16.5	4.6	78.9	78.8	1440	3.46	3.60	40.0	173	1.04	42
S.S.	35	77.0	17.2	4.5	78.3	120.9	1980	4.26	5.41	55.3	191	1.26	31.5
L.S.	30	77.0	17.6	3.7	78.7	123.5	1980	4.01	4.53	52.1	187	1.12	27
G.V.	30	88.0	17.54	3.8	78.66	133.0	1980	4.38	5.02	49.8	180	1.14	31
R.Y.	33	58.0	16.3	5.04	78.66	46.2	900	2.09	2.31	36.0	191	1.10	5

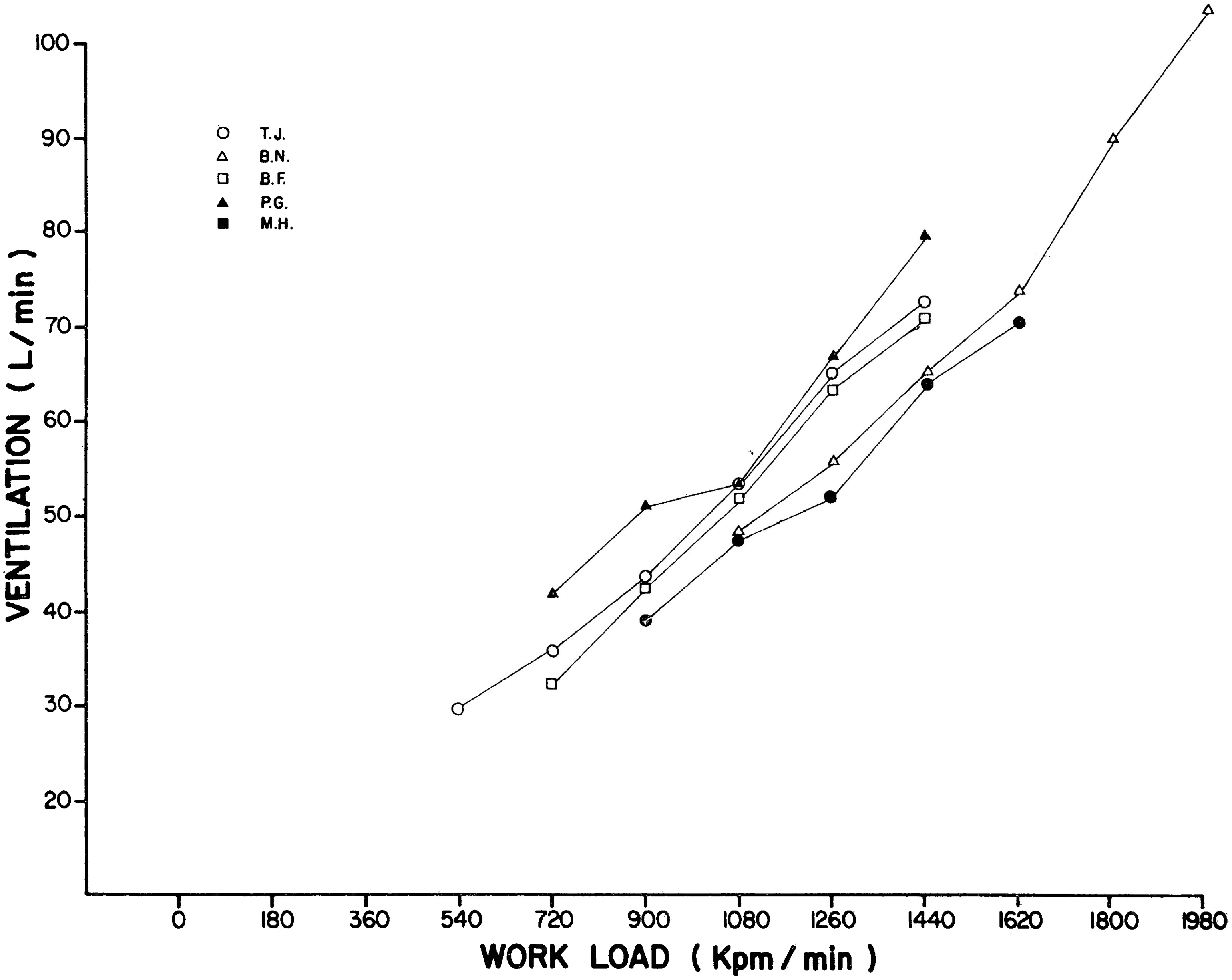
APPENDIX D

VALUES OF VENTILATION (L/MIN) PLOTTED AGAINST RESPECTIVE WORK LOAD TO DETERMINE MAXIMAL AEROBIC CAPACITY FOR THE TRAINED SUBJECTS

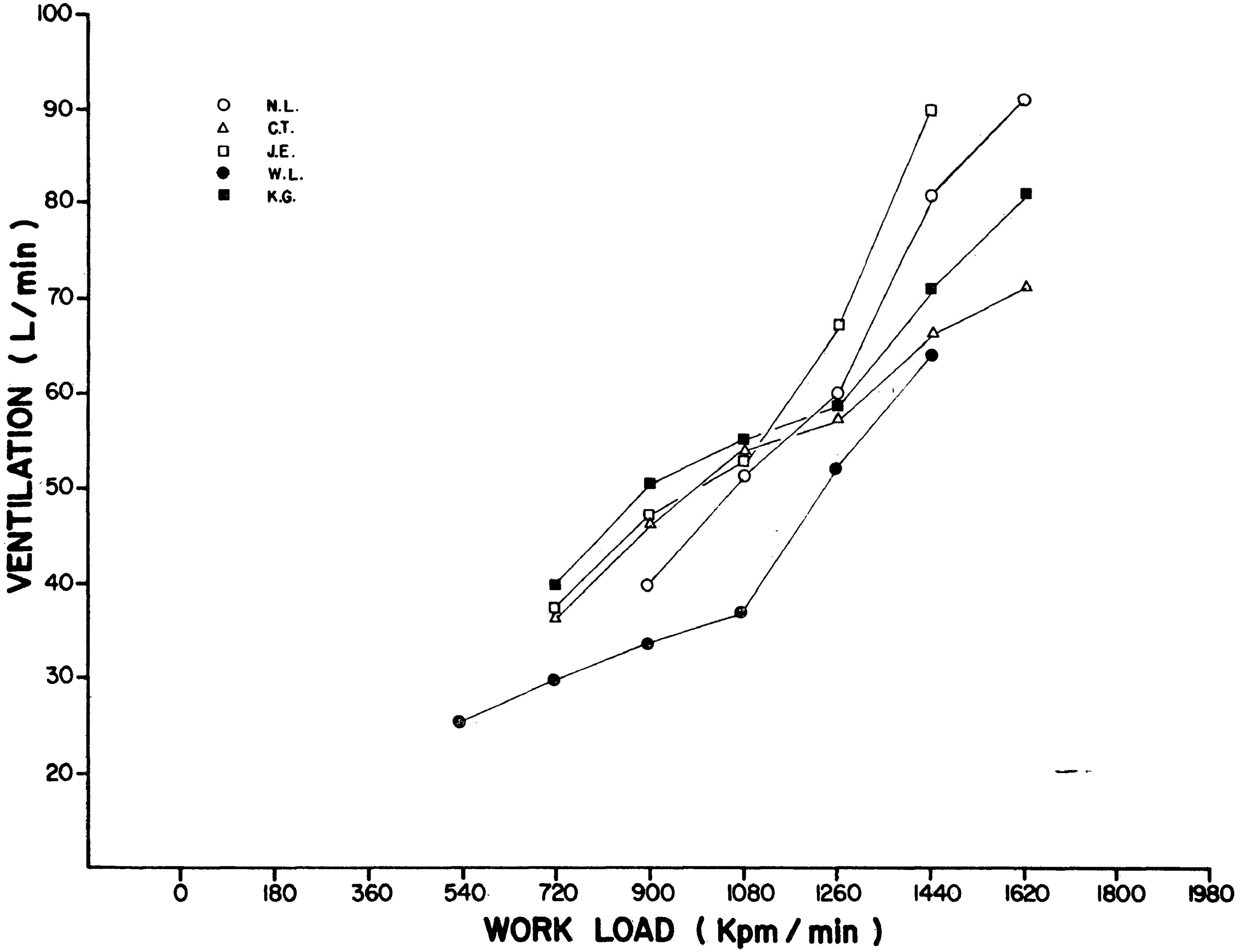

VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
WORK LOAD (Kpm/min)
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
○ J.G.
□ W.M.
▲ R.B.
■ B.R.
● N.J.



○ G.H.
□ E.F.
▲ B.M.
■ P.A.
● N.C.
VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
WORK LOAD (Kpm/min)
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980

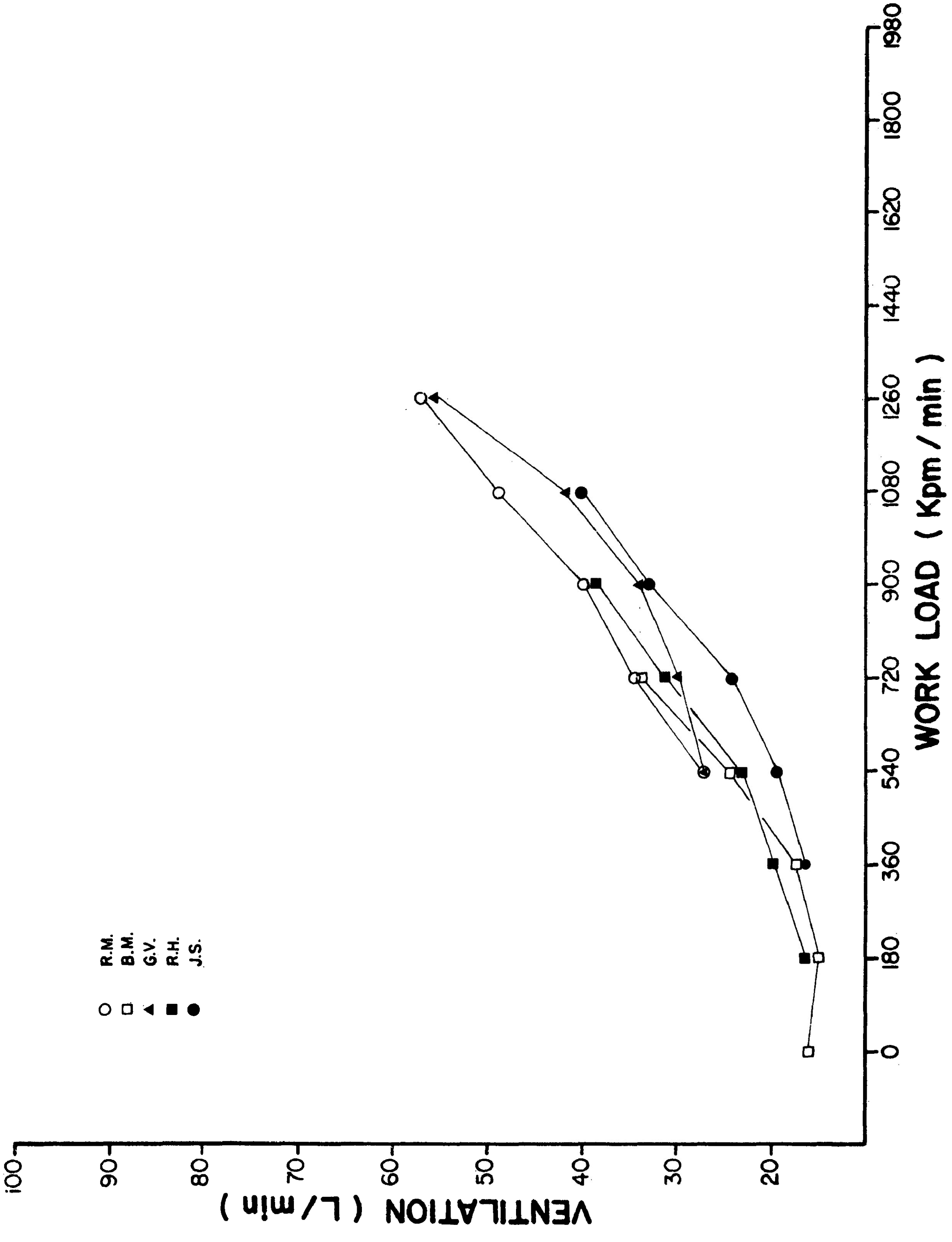


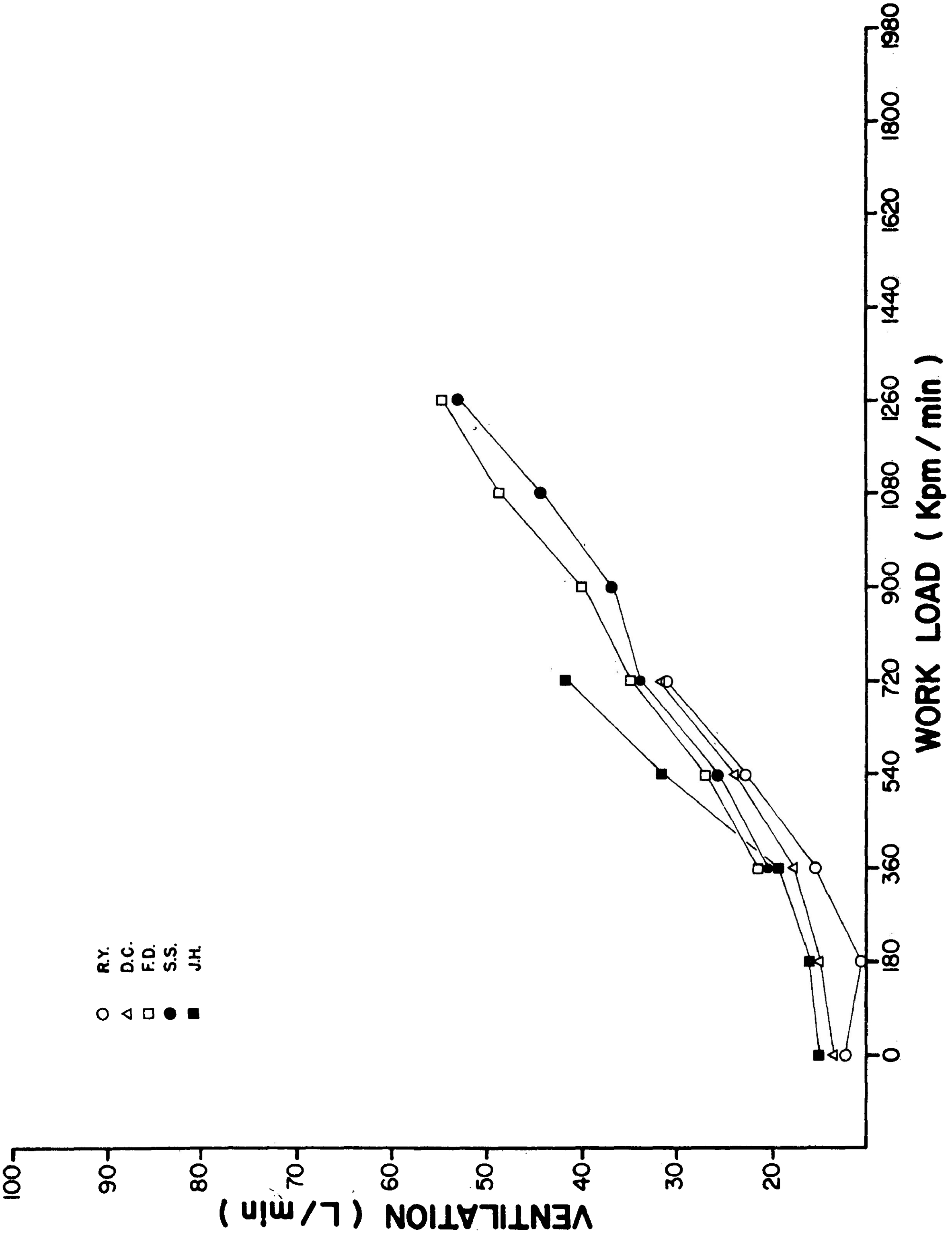
100
90
80
70
60
50
40
30
20
VENTILATION (L/ min)
○ T.J.
△ B.N.
□ B.F.
▲ P.G.
■ M.H.
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
WORK LOAD (Kpm / min)

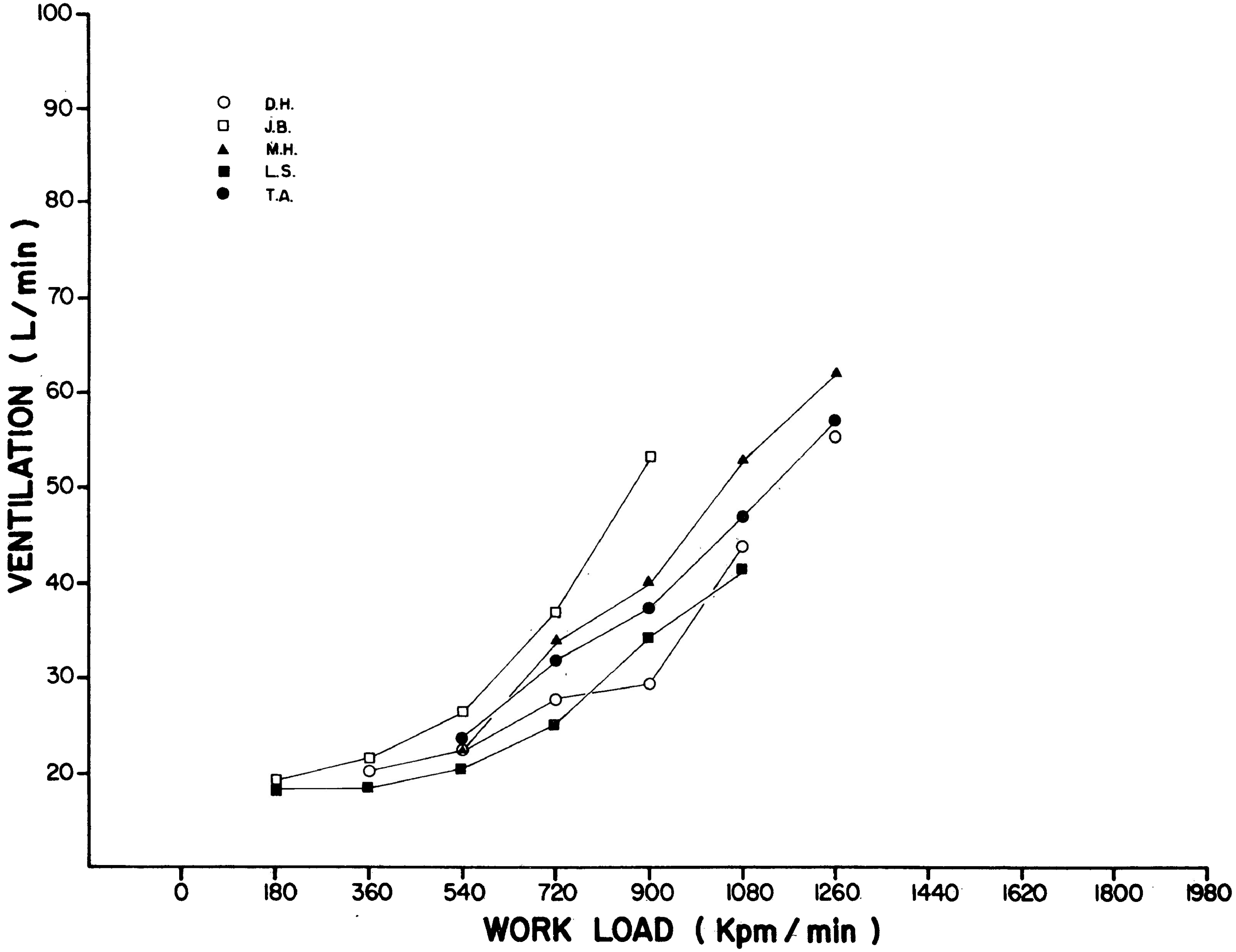

VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
○ N.L.
△ C.T.
□ J.E.
● W.L.
■ K.G.
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
WORK LOAD (Kpm / min)

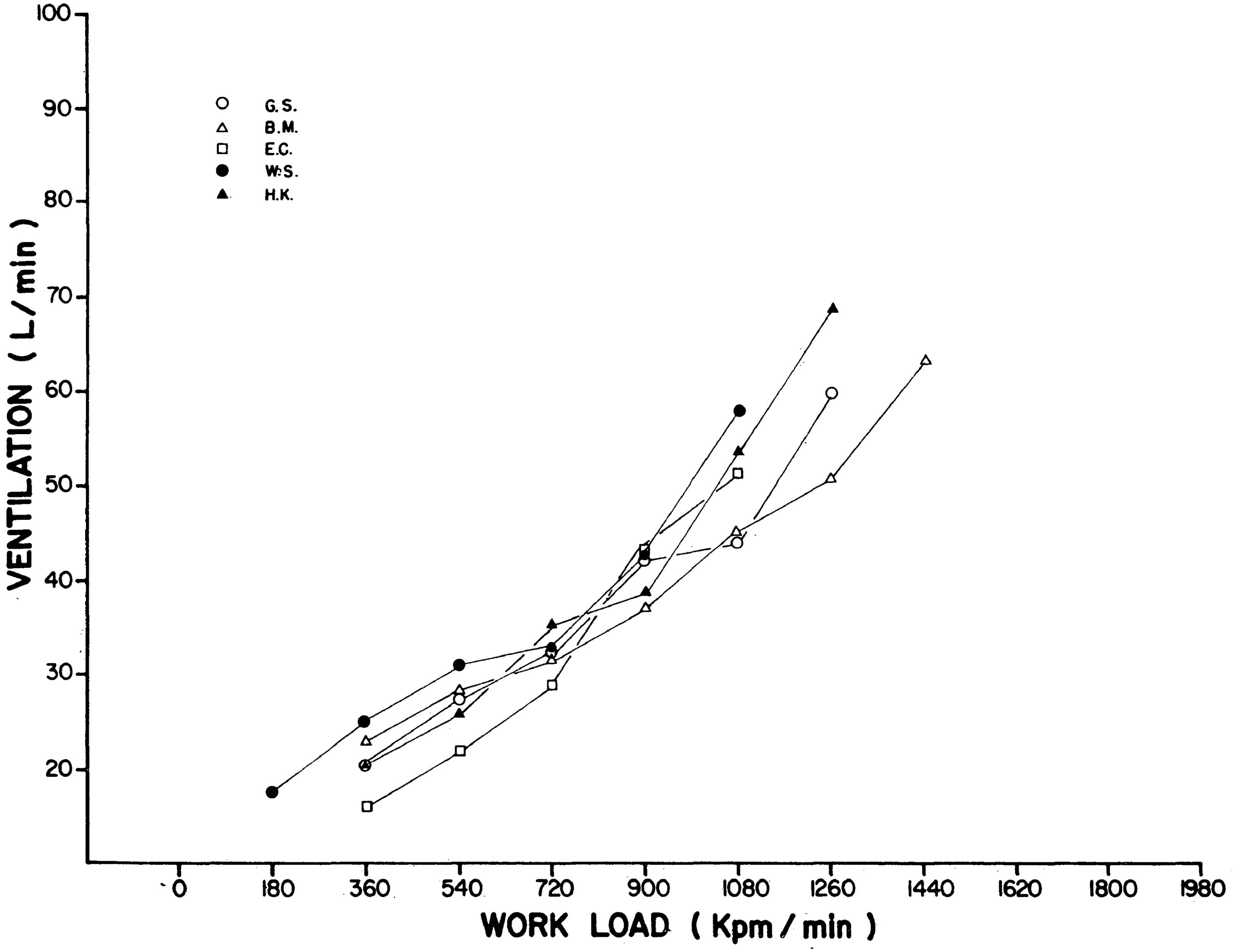
APPENDIX E

VALUES OF VENTILATION (L/MIN) PLOTTED AGAINST RESPECTIVE WORK LOAD TO DETERMINE MAXIMAL AEROBIC CAPACITY FOR THE UNTRAINED SUBJECTS


VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
WORK LOAD (Kpm / min)
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
○ R.M.
□ B.M.
▲ G.V.
■ R.H.
● J.S.


○ R.Y.
△ D.C.
□ F.D.
● S.S.
■ J.H.
VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
WORK LOAD (Kpm / min)
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980


D.H.
J.B.
M.H.
L.S.
T.A.
VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
WORK LOAD (Kpm / min)


VENTILATION (L/min)
100
90
80
70
60
50
40
30
20
WORK LOAD (Kpm/min)
0
180
360
540
720
900
1080
1260
1440
1620
1800
1980
○ G.S.
△ B.M.
□ E.C.
● W.S.
▲ H.K.