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PREDICTION OF MAXIMUM OXYGEN UPTAKE

by
Ray Talbot Hermiston

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PREDICTION OF MAXIMUM OXYGEN UPTAKE

By Ray Talbot Hermiston

Maximum oxygen uptake data were collected on eighty-eight volunteer male subjects between the ages of twenty and sixty-two years during a progressive treadmill walk. A prediction of maximum oxygen uptake was made from age, weight, fat free weight, and submaximum data that included heart rate, respiratory exchange ratio, per cent oxygen extracted, per cent carbon dioxide produced, and tidal volume. The subjects were classified into active and inactive groups on the basis of their habitual physical activity. The active group consisted of the men who participated in vigorous physical activity two or more times per week, for at least one hour per session in the last six months, and the inactive group consisted of men whose habitual level of physical activity was less than this amount.

The data of sixty men were used in the development of six multiple regression equations. The six equations were based on three groups of data; a total prediction group (N=60), a prediction group composed of physically inactive men (N=36), and a prediction group composed of physically active men (N=36). Each group was used to construct a prediction equation that required analysis of expired gas and an equation that did not require such analysis. The data of twenty-eight additional subjects were used to evaluate the six prediction equations. The same physical activity criterion

was used to classify each subject as either active (N=15), or inactive (N=13). Twelve of these subjects were retested to evaluate the reproducibility of the prediction equations. The correlation coefficient between the two predicted maximum oxygen uptakes was 0.91. Published data based on the reproducibility of observed maximum oxygen uptakes show correlation coefficients between 0.91 and 0.96.

The set of multiple regression equations that produced the most accurate prediction results (r=0.90) required both analysis of expired gas and a measure of habitual physical activity. The equations were:

1. For physically active men

   Max. $\dot{V}_{O_2}$ (liters/min) = 2.97 - 0.03 X Age (yrs) + 0.026 X Fat Free Wt (kg) - 0.013 X Heart Rate at 9 min + 0.254 X % CO_2 produced (8-9 min) + 0.33 X Tidal Volume (liters per breath during 1-2 min) - 8.78 X rate of change of Respiratory Exchange Ratio (2-9 min),

2. For physically inactive men

   Max. $\dot{V}_{O_2}$ (liters/min) = 3.62 - 0.02 X Age (yrs) + 0.032 X Fat Free Wt (kg) - 2.59 X Respiratory Exchange Ratio (8-9 min) + 0.25 X Tidal Volume (liters per breath during 8-9 min).

The set of activity related equations that did not require gas analysis were less accurate (r=0.85) but both sets of equations were more accurate than the set of equations based

on the total prediction sample. The contribution of habitual physical activity classification to the prediction of maximum oxygen uptake is evidenced by the lower correlation of 0.55 between the observed maximum oxygen uptake and the predicted maximum oxygen uptake based on the equations developed from the total prediction group.

In a volunteer sample in which there was a clear division between physically active and physically inactive men, an accurate prediction of maximum oxygen uptake was made from regression equations based on measurements of age, weight, and submaximum cardiovascular and respiratory function. These prediction equations must be applied with extreme caution to other samples of adult men in which there are different distributions in age, weight and physical activity.

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The statistical evaluation of the regression equations would not have been possible had the twenty-eight test subjects not given so willfully of both their time and effort.

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DEDICATION

This dissertation is dedicated in memory of my father, Ross Hermiston who in his lifetime made me understand and appreciate the need for both academic and athletic education. Through his past efforts I have realized one of the major goals of my life.

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CHAPTER I

INTRODUCTION

Physical fitness has been investigated either in terms of one specific aspect or as a multivariate concept. Some investigators (11, 25, 38, 46, 71) have made use of physical work capacity tests as the single best measure of fitness. The criterion of performance in a physical work capacity test may be either the maximum oxygen uptake attained or the maximum work load reached. In both procedures the subject continues the test to the point of volitional fatigue. In multivariate terms, total fitness has been assessed through various combinations of the components of strength, speed, agility, power, balance, circulation, and respiration.

Cureton (19), McCloy (41), Barrow (12), and Bookwalter (13) have all proposed test batteries for the appraisal of fitness. Ismail et al. (34) have used a factor analysis technique to produce an equation which contained seven weighted factors for total fitness appraisal. The seven factors included physiologic measures of heart rate, oxygen uptake, and systolic blood pressure, and measures of strength, speed, agility, and coordination.

Taylor (55), and Wahlund (63), advocated the use

of maximum physical work capacity as the best measure of fitness. Their tests were continuous with work loads increased systematically to the point of subjective fatigue. Therefore maximum physical work capacity depends on the willingness of the subject to work anaerobically. In 1947, Sjostrand (51) introduced a work capacity test which terminated at a heart rate of 170 beats per minute. This test design alleviated the problem of motivation in maximum physical work capacity tests. Sjostrand's (51) rationale was based on the simultaneous asymptotic relationship of heart rate and work capacity at maximum work loads. Tests of this type became known as PWC_{170} (51) or PWC_{190} (4). Recently Wyndham et al. (66) have challenged the validity of these procedures. The linear relationship between oxygen uptake and work load up to near maximum values has been widely observed (4, 44, 57, 66). However, as maximum work is approached the oxygen uptake levels off or may even decrease (4, 17, 55). The highest oxygen uptake attained is referred to as maximum aerobic capacity or maximum oxygen uptake.

If fitness is defined as the capacity to do heavy work, then maximum oxygen uptake appears to be the best measure of fitness (30). Unfortunately, maximum oxygen uptake tests require specialized technical equipment, a maximum effort by the subject, and extensive data calculation and analyses. As a result, clinicians have not used maximum aerobic capacity tests as diagnostic tools. A

number of submaximum tests have been proposed as predictors of maximum aerobic capacity (6, 36, 39, 62). These submaximal tests were designed to eliminate the long testing periods and to minimize the danger to older, sedentary subjects inherent in maximum work. Most prediction equations have been based on age, and heart rate at a submaximum work load (6, 39, 62). It appears that a more accurate prediction of maximum oxygen uptake might be made from measurements of more than two submaximum variables. Since differences in the physiologic response to exercise of active and inactive subjects have been reported (11, 26), some assessment of physical activity may be necessary.

Statement of the problem

The purposes of this investigation were:

1. To develop multiple regression equations for the prediction of maximum oxygen uptake from a submaximum treadmill test.
2. To determine the reproducibility of the prediction equations for maximum oxygen uptake from submaximum test results.

Related literature

In 1923 Hill (33) showed that oxygen consumption rises as a linear function of an increasing submaximum work load. Maximum oxygen uptake occurs at the crest of the work load curve. In other words, additional increments in the work load will not produce a significant increment in the

oxygen consumption. Energy to meet this increased difference between total work and the aerobic component is provided by anaerobic processes in the body. Evidence of this anaerobic metabolism is shown by increased lactic acid concentration in the blood (8, 68).

Tests of maximum oxygen uptake are usually performed on stepping blocks, bicycle ergometers, or treadmills. On each piece of equipment there are two basic test designs--a continuous test in which the work load is increased at regular intervals until maximum oxygen uptake is reached, or a discontinuous test in which the subject rests for a set period of time between work increments. Wyndham (68), on the basis of extensive testing, concluded that the treadmill provides the optimal test instrument for use with different populations. Wyndham et al. (68, 69, 71), and Faulkner et al. (26) have both found the discontinuous treadmill test yields the highest values for maximum oxygen uptake. However, both groups concur that similar data can be obtained on the continuous treadmill tests.

Continuous treadmill tests may involve running (52, 68) or walking (11, 26). Taylor (55) has stated that the running tests require a greater degree of skill and coordination. Faulkner et al. (26) concluded that the treadmill run test increases the possibility of injury from falling particularly in untrained, uncoordinated, or fatigued subjects. In addition, older subjects and heterogeneous test groups perform more uniformly at a walking pace than at an unfamiliar running pace (11, 26, 55). Since the

attainment of maximum aerobic capacity may be lowered because of inadequate skill or coordination in the subject's ability to run the best treadmill test appears to be one conducted at a walking pace (11). Walking tests vary in speed from 3.3 mph to 4.6 mph (11, 26, 45, 52, 68).

Balke (11) developed a progressive treadmill test in which the work load was increased by an increase in the grade of 1% per minute. Because of the small increment in work load the oxygen uptake adaptation to the increased load was almost instantaneous (11). Balke contended that the measured values of oxygen uptake during any given minute were comparable to "steady state work" at equivalent work loads. Many modifications in both speed and grade increments have been reported (17, 23, 26, 68). From unpublished data at the University of Michigan (26) it appears that 4.2 mph is the fastest speed at which sedentary older men can walk. As a result Faulkner et al. (26) have utilized a modified form of the Balke and Ware progressive treadmill walk (11). A speed of 4.2 mph was used and the grade remained at zero per cent for the first two minutes. At the two minute mark the grade was increased to two per cent and followed by one per cent increments per minute either to twenty per cent or to volitional fatigue. If the subject walked for more than twenty minutes there were no further work increments and the subject continued to walk at twenty per cent and 4.2 mph until fatigued. As reported by Balke and Ware (11), and Faulkner et al. (26) test duration time for most

subjects was 14 to 16 minutes; with 90 per cent completing less than 23 minutes and only 1 per cent continuing for more than 28 minutes.

In 1966, Wyndham et al. (68) presented data which showed a positive correlation between body weight and oxygen uptake. These investigators calculated a regression line for oxygen uptake with body weight as the independent variable. The regression equation (68) was $V = 0.0426 \cdot W + 0.3298$ where V is the maximum oxygen uptake and W is the weight in kilograms. The correlation coefficient between the two variables was 0.78. This relationship signified that the heavier men tended to have a greater maximum oxygen uptake. For the adult men in the study conducted by Astrand (2), the correlation coefficient between body weight and maximum oxygen uptake was 0.66. Other studies of homogeneous samples of adult men have reported similar relationships between weight and maximum oxygen uptake (29, 61, 65). However, in heterogeneous samples of adult men the relationship is much less precise. In heterogeneous samples, Welch et al. (65) and Andersen and Hermansen (1) have reported correlations that are not significantly different from zero.

Since oxygen uptake utilization is greatly increased in muscle tissue during exercise the relationship between fat free weight and maximum oxygen uptake is higher than that between body weight (fat free weight plus adipose tissue) and maximum oxygen uptake. The data

of Buskirk and Taylor (16) and Welch et al. (65) indicated that fat free weight correlates 0.85 and 0.65 respectively with maximum oxygen uptake as compared to the correlations of 0.75 and 0.55 between body weight and maximum oxygen uptake.

Yuhasz (72) developed an equation for the estimation of fat free weight from six subcutaneous fat measures. The estimate from the regression equation correlated highly with direct densiometric results ($r = 0.82$). Since fat measures at different sites correlate highly a new regression equation utilizing four measures was developed at the University of Michigan (26). The correlation between the two subcutaneous fat equations was 0.90. Fat free body weight calculated by using the formula developed at Michigan produced results similar to the data of Welch et al. (65).

Robinson (46) has shown a definite negative relationship between age and maximum oxygen uptake. The data published by Astrand (2) and Von Dobeln et al. (62) concurred with that of Robinson. Astrand's age factor was calculated as a constant which varied from 1.00 at 25 years of age to 0.65 at 65 years. According to Von Dobeln et al. (62) the age to oxygen uptake relationship varied in a negative exponential manner of the order of $e^{-0.00884t}$ where t is the subject's age. Balke (10) and Faulkner et al. (26) have found that the age decrement is less for physically active than for sedentary individuals.

The heart rate to oxygen uptake relation appears to be linearly related throughout most of the work capacity range (7, 26, 66, 68). Balke and Ware (11) reported a variation of heart rate response to a given work load by various fitness groups among air force personnel. On the same physical work capacity test, the heart rate of the unfit subjects reached maximum levels in approximately half the time period it took the heart rate of the fit personnel to reach maximum. Wyndham (67) and others (11, 26, 51, 55) have investigated heart rate slopes from resting to maximum work loads. Although the rate of change of heart rate response to work varied among individuals most subjects were able to reach a heart rate in excess of 170 beats/min regardless of age. Wyndham et al. (66) plotted heart rate response and oxygen uptake values with increasing work loads. They concluded that the heart rate reached its maximum values before oxygen uptake reached a plateau. As a result, Wyndham et al. (66) concluded that it was necessary to use a number of submaximal heart rates to fit a straight line which would predict maximum heart rate. These results suggest that the prediction of maximum oxygen uptake by PWC_{170} (51) would be below the true maximum oxygen uptake. Wyndham et al. (66) pointed out that the difference between maximum oxygen uptake predicted from heart rate extrapolated to a maximum linear value of 180 beats/min and the true maximum oxygen uptake observed at its asymptotic maximum (180 beats also) averaged 0.32 liters $\pm$ 0.14 liters per minute.

In 1947, Wahlund (63) reported a positive linear relationship between oxygen uptake and respiratory frequency. Wahlund concluded that "pulse and respiratory rates were the most suitable indicators of working capacity." Sharkey et al. (49) reported less variation in the relationship between oxygen uptake and respiratory rate than between heart rate and oxygen uptake. Others (11, 55) have reported linear relationships between respiratory rate and oxygen uptake. These data suggest that the respiratory rate might be useful in predictions of maximum oxygen uptake.

Minute ventilation is also an integral part of oxygen uptake. Many investigators (39, 42, 44, 69) have indicated a linear relationship between minute ventilation and work load until near maximum load. Hickman et al. (31) reported large variations in initial ventilatory volumes for unfit subjects. However they inferred that the relationship was basically linear. Hermansen and Andersen (29) have reported that increased ventilation (hyperventilation) occurred at approximately 80 per cent of maximum aerobic capacity. Others (11, 18, 44) have also reported this change in slope of ventilation vs. oxygen uptake graphs as extreme work loads are reached. Balke and Ware (11) concluded that minute ventilation had limited use as a predictor of oxygen uptake. However, they also stated "greater work capacity is associated with a greater respiratory efficiency and usually with a greater maximum breathing capacity."

Definite interactions occur among the per cent of

expired carbon dioxide, the percentage of oxygen extracted, and the minute ventilation. Although the minute ventilation was 18 per cent less in swimming compared to running Magel and Faulkner (38) found swimmers could attain the same maximum oxygen uptake in both activities by extracting more oxygen while swimming. Ventilation equivalents ($\dot{V}_E$ / $\dot{V}_{O2}$ STPD) were 26.2 swimming and 30.7 running.

Balke and Ware (11) reported that the more fit person extracted a greater percentage of oxygen per liter of inspired air. Others (2, 46) have reported that oxygen extraction is negatively related to age. Mitchell et al. (44) reported the main circulatory determinants of oxygen uptake must be cardiac output and arterio-venous oxygen difference. This arterio-venous oxygen difference is widened by lowering the mixed venous oxygen level. Differences were increased from five volumes per cent at rest to approximately fourteen volumes per cent at maximum work levels. Freedman et al. (27) reported similar submaximal responses by trained and untrained subjects with respect to increased arterio-venous oxygen differences (up to approximately 2 liters of oxygen uptake per minute).

Many investigators (26, 35, 44, 54) have observed an increase in the fraction of carbon dioxide in the expired gas with the onset of exercise. A plateau was observed within a few minutes of the start of exercise. This plateau between work load and per cent of expired carbon dioxide remained essentially constant until near maximum work loads.

As the work load approached maximum proportions the percentage of carbon dioxide dropped slightly. In exercise the percentage of oxygen extracted per minute decreases at a faster rate than the percentage of carbon dioxide expired decreases. The result is a gradual increase in the respiratory exchange ratio (35).

Prediction equations of maximum oxygen uptake

In 1954 Astrand and Ryhming (6) published a nomogram for the prediction of maximum oxygen uptake from a submaximum work level on either a bicycle ergometer or a step test. For men, the submaximum work loads were either cycling at a speed of 50 rpms and a load of 1200 kpms or stepping at a cadence of 22.5 steps per minute on a 40 cm bench. The Astrand nomogram was developed from four basic assumptions: 1) that heart rate and oxygen uptake are linearly related from rest to maximum values, 2) that individual deviations from the population mean of maximum heart rates are small, 3) that the intercept at zero work load between per cent of maximum oxygen uptake and heart rate occurred at sixty beats per minute for males, and 4) that for all individuals a linear relationship exists between oxygen uptake and work load. The nomogram was based on the relationship between heart rate in beats per minute and per cent of maximum oxygen uptake demanded at submaximum work loads.

From the data collected on 30 healthy men 18-30 years of age, Astrand and Ryhming calculated the heart

rate at both 50 per cent and 70 per cent of maximum oxygen consumption. At 50 per cent the heart rate was 128 beats per minute while at 70 per cent the heart rate rose to 154 beats. One scale of the nomogram was based on this linear relationship (4). By assuming a constant work efficiency of 24 per cent (6, 63) Astrand and Ryhming were able to calculate submaximum oxygen uptake for a given work load on the ergometer. An equivalent work load scale was developed for the step test from the subject's weight, bench height, and stepping cadence. This oxygen uptake to work load relationship was used to set up the second scale of the nomogram.

In 1960 Astrand (2) adjusted the prediction nomogram for age and sex. The male age correction factor was developed from a sample of 129 men between the ages of 20 and 69 years. The per cent difference between the observed and predicted maximum oxygen uptakes were calculated using the formula;

$$\% \text{ difference} = \frac{(N - U) \cdot 100}{U}$$

where N is the calculated maximum oxygen uptake and U is the observed maximum oxygen uptake. By plotting this calculated per cent difference against age a correction factor was produced. This age correction factor varied from 1.0 for 25 year olds to 0.65 for 65 year old men.

In 1961, the Astrand-Ryhming (6) premises that heart rate and maximum oxygen uptake are linearly related at maximum work loads and that the intercept of heart rate

with the per cent of maximum oxygen uptake utilized at zero per cent work load occurred at 60 beats per minute were investigated by Maritz et al. (39) and Wyndham (66). As a result they proposed that maximum oxygen uptake be predicted by the following method (39): 1) select four submaximum work loads and determine the subject's heart rate at each work load, 2) estimate the submaximum oxygen uptake for each of the submaximal work loads from an oxygen uptake--work load graph, 3) fit a straight line through the four oxygen uptake-heart rate intercepts and extrapolate the line to a heart rate of 180 beats per minute. The corresponding oxygen uptake on the abscissa was then the subject's maximum oxygen uptake. The submaximum bicycle test used by Maritz et al. (39) was continuous to a heart rate of approximately 170 beats per minute.

In 1960 Issekutz et al. (36) published data indicating a linear relationship existed between excess carbon dioxide expired and minute ventilation. These data led to the formula: excess CO_2 = total CO_2 - 0.75 · O_2 where 0.75 represented an estimate of the true metabolic respiratory quotient at rest. This formula could be transformed:

$$\frac{\text{excess } CO_2}{O_2} = \frac{(\text{total } CO_2)}{O_2} - 0.75$$

or $\Delta RQ = RQ - 0.75$ where RQ is the measured respiratory exchange ratio. As reported in 1961 Issekutz et al. (36) utilized a ΔRQ of 0.4 units (ΔRQ=work RQ-0.75). They calculated this 0.4 value by plotting the oxygen uptake of

5 subjects against their respective work loads. They also plotted ΔRQ against work load. The maximum aerobic capacity occurred for all subjects at a ΔRQ of approximately 0.4 (range 0.38 to 0.42). Therefore an average ΔRQ was set at 0.4 or a respiratory exchange ratio of 1.15. In addition the resting respiratory exchange ratio while the subject sat on the bicycle ergometer was considered to be above the basal RQ of 0.75. They calculated this pre-exercise respiratory exchange ratio to be 0.83 units. This pre-exercise respiratory exchange ratio was 0.08 above a resting respiratory quotient.

Utilizing the data of the 1960 study (35) Issekutz et al. (36) developed a prediction equation for maximum oxygen uptake. The equation was:

$$\text{Max } \dot{V}O_2 \text{ (liters/min)} = 2 \cdot \frac{(\log 0.4 - \log 0.08)}{(\log \Delta RQ - \log 0.08)} \cdot W \cdot \frac{1}{1000} \cdot 0.32$$

where ΔRQ is the measured respiratory exchange ratio minus 0.75 and W is the submaximum work load in kpm/min.

The submaximal test consisted of a 5 to 6 minute warming up period at 450 kpm/min for all men, followed by a 10 minute rest period. The actual test was a 5 minute ergometer ride at a load of 750 or 900 kgm/min and a pedalling frequency of 50 rpms. Expired gas was collected for one minute after 3-1/2 to 4 minutes of work. The expired gas was analyzed to determine the respiratory exchange ratio for each subject.

In 1954, Brody (14) published a series of mathematical

equations relating metabolic rate and descrete physical variables. Brody reported the oxygen uptake vs. age relation in the form e^{kt} where t was the age in years and k was a negative constant. Most other physical variables were expressed generally as exponential equations of the form $Y = kV^{\alpha}$ where Y is the oxygen uptake, V the physical variable, α an exponential constant, and k a constant.

In 1967, Von Dobeln et al. (62) introduced a prediction equation utilizing the formulas published by Brody (14). Von Dobeln et al. experimented with five variables in their prediction equation. The variables were: heart rate at maximum work load, submaximal work load in kpm/min, heart rate at the submaximal work load, age, and skeletal weight. These variables were analyzed in the exponential form:

$Y = kA^{\alpha} \cdot B^{\beta} \cdot C^{\gamma}$ where k, α, β, γ were constants. The prediction formula published was of the form:

$$\text{Max } \dot{V}O_2 = k(M+a)^{\alpha} \cdot \left(\frac{L}{H+a}\right)^{\beta} \cdot S^{\gamma} \cdot e^{rt}$$

where $k, \alpha, \beta, \gamma, r$ are constants, M is the maximum heart rate, "a" an arbitrary resting heart rate, H the submaximal heart rate at load L, S is the skeletal weight (62) and t is the subject's age.

The constant "a" was set at 60 to remove some of the covariance effect of resting heart rate (6). The prediction term $\left(\frac{L}{H+a}\right)$ was also derived from data published by Astrand and Ryhming. The Von Dobeln group found by trial and error

computer analysis that both maximum heart rate and body weight explained an insignificant portion of the variance of the maximum oxygen uptake. Their final prediction equation was Max $\dot{V}O_2 = 1.29 \left(\frac{L}{H - 60}\right)^{0.5} \cdot e^{-0.00884t}$.

Von Dobeln et al. (62) developed their equation from data on 84 male construction workers aged 30-70 years. The submaximal data were collected at the 4^{th}, 5^{th}, or 6^{th} minute of a progressive ergometer test (62). During these data collection periods heart rates above 170 or below 125 beats/min were disregarded. If the heart rate continued to increase from the 4^{th} to the 7^{th} minute the highest rate was used, otherwise, the mean value of the heart rates between 125 and 170 beats/min was used. The appropriate value of load in kpm/min was also used.

Prediction equation comparisons

In 1965 Glassford et al. (28) compared results of maximum oxygen uptake predicted by the Astrand Ryhming nomogram with two treadmill and one bicycle ergometer tests. Twenty-four healthy males between the ages of 17 and 23 years were used as subjects. Their weights ranged from 63 to 86 kilograms. The results indicated that the two treadmill tests (44, 57) and the Astrand Ryhming nomogram yielded significantly higher mean maximum oxygen uptakes than did the direct ergometer test. These results concurred with results reported by Hettinger et al. (30) in 1960. Glassford et al. also indicated that the zero order correlation

coefficients between the nomogram results and the three maximum uptake tests were as high (r=0.70) as the correlations among the other tests. In conclusion, Glassford et al. (28) reported that the variance about the mean predicted maximum oxygen uptake was significantly greater than the variance about the observed maximum oxygen uptakes. They indicated that this increased variance should be investigated thoroughly before the nomogram is used extensively.

In a study utilizing 28 subjects 20 to 30 years of age Hettinger et al. (30) compared maximum oxygen uptake predicted from the nomogram with actual uptake values on a bicycle ergometer test. A mean predicted maximum oxygen uptake of 2.62 liters per minute was obtained compared to an actual maximum uptake of 2.38 liters per minute. The difference was significant ($P < .01$). Hettinger did not report the correlation coefficient between the observed and predicted maximum oxygen uptake values but only that the correlation coefficient was significantly different from zero ($P < .01$).

Shephard (50) reported no statistical mean difference between observed maximum oxygen uptakes and the derived maximum oxygen uptake values for both the Astrand Ryhming nomogram and the Issekutz formula (62). The correlations were reported at 0.87 and 0.92 respectively. Shephard used ten sedentary subjects in the comparison study.

Comparison results reported by deVries et al. (20) are similar to other published comparisons (28, 30) for

maximum oxygen uptake predictions using the Astrand Ryhming nomogram. DeVries also used a modified Issekutz prediction formula and reported that the predicted maximum oxygen uptakes were not significantly different from the direct test mean. However the correlation was only 0.49. The modified Issekutz datawere collected at an earlier time than the original prediction formula requirements.

Although habitual physical activity would appear to be an important determinant of maximum oxygen uptake, data are not available to clearly describe the relationship. Durnin (22) is critical of the questionnaire method for the assessment of activity patterns, due to the tendency for the inactive subjects to overestimate and the active subjects to underestimate their activity patterns. Durnin preferred the "diary type data collection." This diary must be on a sequence of days rather than by recall. Keys et al. (37) utilized a three division break for physical activity. Their divisions were, sedentary or light activity, moderately active, and highly active. They suggested that additional categories of bed ridden, and extremely active could be added but that only the coarse graduations of the first three groups were justified at present. Keys' technique of assessment was by personal interview and classification was primarily based on occupations of the subjects.

In general the prediction of maximum oxygen uptake made by Astrand (2), Maritz et al. (36), Issekutz et al. (39) and Von Dobeln et al. (62) were developed for use with a

bicycle ergometer. In each of the four submaximal tests, heart rate response varied between 125 and 170 beats per minute. Three of the four predictions utilized some measure of submaximum heart rate as a prediction term (6, 36, 62). Two of these equations (6, 62) assumed a heart rate of 60 beats per minute at zero load, while in the third equation (39) the heart rate prediction was made from the slope of a series of four submaximum heart rates. Three of the equations utilized the heart rate, oxygen uptake, and work load interrelationships to predict maximum oxygen uptake. The fourth prediction equation (36) was based on the linear relationship between the respiratory exchange ratio and oxygen uptake during increasing work loads. Only two equations (6, 62) included an age correction factor. Although both respiratory rate and minute ventilation (11, 49, 63) have been suggested as possible predictors of maximum oxygen uptake none of the equations has utilized these variables.

Multiple regression as a prediction procedure

Multiple regression equations are used to relate a number of independent variables to one dependent variable. A simple zero order regression equation may not be the best method of explaining relationships when the dependent variable is influenced by several independent variables. In multiple regression equations all independent terms are usually to the first power.

Multiple regression equations can be written (53)

$$\mu_{y.12...k} = \mu_{y.\overline{12...k}} + \beta_1 X_1 + \ldots \beta_k X_k$$

where $\mu_{y.12...k}$ represents the mean "Y" for the population of "Y's" at a fixed set of $X_1, \ldots X_k$ and $\mu_{y.\overline{12...k}}$ represents the population mean when the fixed set is $(\bar{x}, \ldots \bar{x}_k)$.

The multiple correlation coefficient measures the degree of association between the observed "Y" values and a function of the independent variables. This function determines the regression plane. Multiple correlation coefficients are denoted by $R_{y.12..k(21)}$.

In order to compare the contribution of each independent variable to the multiple regression equation Ezekiel and Fox (24) utilized a standard regression coefficient. These coefficients are the partial regression coefficients expressed in standard measure, that is, a deviation from the mean in units of standard deviation.

$$\text{i.e., Standard coefficient } b'_i = b_i \cdot \frac{S_i}{S_y}$$

Since "b" is independent of the original units of measurement comparisons among standard regression coefficients can be made to indicate their relative importance in estimating or predicting "Y".

A number of submaximal variables may be independently related to maximum oxygen uptake. Therefore a multiple regression analysis is appropriate. Furthermore, many variables are interrelated and a stepwise regression procedure allows

the selection of independent variables that are not highly related to other independent terms.

CHAPTER II

METHODOLOGY

Eighty-eight volunteer men between the ages of twenty and sixty-two years, participated in this study. All men resided in the community of Ann Arbor, Michigan. These subjects were divided into two groups: 1) the total prediction group and 2) the total test group. The total prediction group consisted of sixty men whose data were used to develop six multiple regression equations for predicting maximum oxygen uptake. The total test group was a sample of twenty-eight men whose data were used to evaluate the reliability and reproducibility of the prediction equations.

The sixty men in the total prediction group were members of a study "The Comparison of Selected Tests of Physical Work Capacity" (26) at the University of Michigan. In this physical work capacity study the sixty men were divided into ten homogeneous groups each containing six subjects. Each group was homogeneous with respect to age, weight, and physical activity.

Keys et al. (37) reported that physical activity may be an important facet in the assessment of physical fitness. The sixty men of the total prediction group were divided into two subgroups based on habitual physical

activity patterns. One subgroup was designated "the active prediction group" and the other subgroup was designated "the inactive prediction group." The division was based on the following criteria: 1) men who participated regularly in vigorous physical activity two or more times per week, for at least one hour per session, in the past six months were classified as active; and 2) men who have participated less than two hours per week in vigorous physical activity were considered to be inactive. Since physical activity is difficult to assess, a number of subjects in any population might be classified as either active or inactive, depending on the interviewer's frame of reference. To allow for such variability in the classification of subjects into physical activity groups, the data for twelve subjects with the highest habitual physical activity levels in the inactive group were also included in the active group. These twelve subjects included 3 subjects from each of the four 10 year age groups from 20 through 60 years of age. Thus the total prediction group (N=60) was divided into two interlocking subgroups, an active prediction group (N=36), and an inactive prediction group (N=36), with the data of twelve subjects included in both groups.

The total test group (N=28) was also divided into an active test group (N=15), and an inactive test group (N=13). The inactive test group averaged thirteen years younger (29-42 years) than the inactive prediction group and the active test group averaged six years younger than

the active prediction group. Medical supervision required for maximum oxygen uptake tests which involve inactive men over twenty-five years of age or active men over forty years was available for the men in the prediction group. Since medical supervision was not available for the collection of data on the test group, younger subjects were recruited.

Test Procedures

All testing was done in a temperature and humidity controlled laboratory at the University of Michigan (21°C and 50% relative humidity). All subjects reported to the laboratory dressed in gym shorts and shoes. They were weighed without shoes. In addition four fat measures were taken as specified by Yuhasz (72) at the triceps, subscapular, suprailiac, and abdominal sites. Fat free weight was calculated using a modification (26) of the Yuhasz equation (72). The modified equation was; FFW = WT. - [(5.783 + .153 · Σ 4 fat folds) x Wt.] where FFW is fat free weight in kilograms, Wt. is body weight in kilograms and Σ 4 fat folds is the sum of the specific fat folds in millimeters at the triceps, subscapular, suprailiac, and abdominal sites. After age, weight and the fat fold measures were recorded, a bipolar chest lead was connected in the C5- C5R positions. The lead was connected directly to a Sanborn Twin-Viso Recorded (model no. 60-1300). The breathing apparatus which consisted of a Collins Triple J valve attached to an adjustable helmet, was fitted to the subject. A nose-clip was used to occlude the nasal passages. The output

of the triple J valve was connected by way of a flexible hose (1-1/2" I.D.) to a gas mixing canister. The canister led directly into a chain compensated 600 liter Tissot gasometer. The volume of gas expired and the respiratory rate during gas collection were recorded on a kymograph connected to the gasometer. Gas samples were drawn from the six liter mixing canister in 50 c.c. glass syringes. The gas was drawn slowly into the syringe during the 40 seconds from 10 seconds after gas collection started to 10 seconds before the end of each gas collection. The resistance of the collecting system was less than 4 m.m. of water. All gas samples were analyzed for oxygen, carbon dioxide, and nitrogen in a Fisher/Hamilton gas partitioner (model no. 29).

The subject started walking on the treadmill at zero per cent grade and a speed of 4.2 miles per hour. After two minutes of walking at zero per cent the treadmill grade was raised to two per cent. At the end of each consecutive minute of walking the grade was increased by one per cent. Thus the per cent grade of the treadmill was the same as the number of minutes the subject had walked. When the grade reached twenty per cent the subject continued to walk but there were no further grade increments.

At the end of the first minute of walking expired gas was collected for one minute. At the end of the seventh minute another one minute gas collection was taken. As the subject approached his maximum aerobic capacity continuous

minute gas collections were taken. The test was terminated when the subject reached volitional fatigue. In all cases at least two gas collections were taken at maximum levels. A five second electrocardiogram was recorded during the last five seconds of each gas collection period.

Twelve of the twenty-eight test group subjects returned to the laboratory at least two days after their maximum oxygen uptake tests. These men were retested following the same procedure except that their treadmill test ended after the eight minute gas collection. The data of these twelve men were used to determine the reproducibility of the prediction equations.

In all tests, at the two submaximum levels (1-2 minutes and 8-9 minutes) respiratory rate (breaths/minute), minute ventilation (liters/minute, STPD), and heart rate (beats/minute) were recorded. From the expired gas, oxygen uptake (liters/minute), respiratory exchange ratio, and tidal volume (liters/minute) were derived for each gas collection period.

Several investigators (11, 36, 39) have suggested that the rate of change of some physiologic variables might be used as possible indicators of maximum oxygen uptake. As a result five rates of change (slope) between the 1-2 minute gas collections and the 8-9 minute gas collections were calculated for the following variables: 1) respiratory rate, 2) minute ventilation, 3) oxygen uptake, 4) respiratory exchange ratio, and 5) heart rate. The twenty-five variables

presented in Table 1 were selected as possible predictors of maximum aerobic capacity. All variables were punched on IBM cards.

Means and standard deviations were calculated for each of the twenty-five variables for the total prediction group, the active prediction group, the inactive prediction group, the active test group, and the inactive test group.

A computer program was written to use these twenty-five variables in a relocatable matrix. The program was designed to compute a basic multiple regression of the form:

$$Y' = a + C_1X_1 + C_2X_2 + \ldots CnXn.$$

The computer program was constructed for on-line access through the console typewriter. As each variable was added, in turn, to a particular stage of the multiple regression equation (e.g., $Y' = a + C_1X_1$) the coefficient of determination was computed and recorded on the console typewriter. After the contribution of each of the twenty-five variables had been calculated for a particular stage, the operator chose which variable was to be accepted in the C_1X_1 position.

Two equations were developed from the data on the total prediction group, the active prediction group, and the inactive prediction group. One set of equations which utilized all twenty-five variables as possible predictors were designated as the equations that required gas analysis. The other set of equations were designated as the equations that did not require gas analysis.

TABLE 1

TWENTY-FIVE VARIABLES USED AS POSSIBLE PREDICTORS IN THE MULTIPLE REGRESSION EQUATIONS

Variable Name
Age (years)
Body weight (kgs.)
Fat free weight (kgs.)
Submaximal heart rate difference

Variable Name	1-2 minute collection	8-9 minute collection	Rate of change 2-9 minutes
Tidal Volume (liters/min.)	x	x	
Oxygen extracted (per cent)	x	x	
Carbon Dioxide expired (per cent)	x	x	
Respiratory frequency (breaths/min.)	x	x	x
Minute volume (liters/ min.) (STPD)	x	x	x
Respiratory exchange ratio	x	x	x
Oxygen uptake (liters/min.)	x	x	x
Heart rate (beats/min.)	x	x	x

The criteria used to determine which variable was to be added at each stage were:

1) The variable which produced the largest coefficient of determination, and thus the largest partial correlation with respect to the dependent variable, was added at each stage.

2) Stepwise additions to the multiple regression equations were continued until the addition of the next independent variable would have contributed less than two per cent to the coefficient of determination.

Since these criteria had not been used previously an established stepwise multiple regression equation (58) was used to evaluate them. The results of the alternate procedure, which was designed to include terms or delete terms based on a significant F ratio previously established, can be found in Appendix C, page 107. There were no differences in the stepwise selection of variables using the alternate program.

In order to evaluate the six specific equations developed through stepwise multiple regression techniques the submaximal data of the twenty-eight test group subjects were used. The predicted maximum oxygen uptakes for each subject were compared to each subject's observed maximum oxygen uptake. These comparisons were analyzed by paired "t" tests and zero order correlation techniques. The test-retest data were also analyzed by paired "t" tests and correlation coefficients.

In order to make comparisons between the predictions of maximum oxygen uptake obtained in the present study and predictions obtained in the published literature (6, 36, 39, 62) the submaximal data of the 60 subjects of the prediction group were also used to predict maximum oxygen uptakes. The data were analyzed on a 7090 IBM computer at the University of Michigan. The stepwise procedure for the equation construction was developed on a 1620 II IBM computer at the University of Windsor.

CHAPTER III

PRESENTATION AND ANALYSIS OF THE DATA

The mean physical characteristics of the five groups used in this study are presented in Table 2. The five groups were the total prediction group (n=60), the active prediction group (n=36), the inactive prediction group (n=36), the active test group (n=15), and the inactive test group (n=13). The means and standard deviations for all independent variables used in developing the multiple regression equations from the data on the active prediction group and the inactive prediction group are presented in Table 3. Comparable data for the active test group and the inactive test group are presented in Table 4. Only the variables which were used in the multiple regression equations are presented in Table 3 and Table 4. Means and standard deviations for all twenty-five variables for each group are shown in Appendix D (p. 133).

The correlation between body weight and oxygen uptake was 0.17 for the total prediction group, 0.38 for the active prediction group, and 0.61 for the inactive prediction group. When the correlations were calculated between fat free body weight and oxygen uptake for these groups the correlation coefficients were, for the total prediction group 0.36, for the active prediction group 0.48, and for the inactive

TABLE 2

MEANS AND STANDARD DEVIATIONS DESCRIBING THE PHYSICAL CHARACTERISTICS OF THE FIVE GROUPS

GROUP	AGE (Years)		WEIGHT (Kgs)		FAT FREE WEIGHT (Kgs)		MAXIMUM OXYGEN UPTAKE (liters/min)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TOTAL PREDICTION GROUP (N=60)	38	11.5	79.4	8.5	67.1	6.8	3.00	.63
ACTIVE PREDICTION GROUP (N=36)	34	9.9	78.5	8.7	67.3	7.0	3.26	.52
INACTIVE PREDICTION GROUP (N=36)	42	9.9	82.4	8.9	68.6	7.3	2.72	.47
ACTIVE TEST GROUP (N=15)	28	6.3	76.8	7.9	65.2	5.8	3.63	.32
INACTIVE TEST GROUP (N=13)	29	8.0	78.4	9.9	64.2	5.5	2.96	.25

TABLE 3

MEANS AND STANDARD DEVIATIONS OF ALL VARIABLES USED IN THE DEVELOPMENT OF THE MULTIPLE REGRESSION EQUATIONS FOR TWO PREDICTION GROUPS

Variables	Time of Collection (Min.)	Active Group (N=36)		Inactive Group (N=36)	
		Mean	SD	Mean	SD
AGE (years)		34	10	42	10
FAT FREE WEIGHT (kgs.)		67.30	7.00	68.62	7.28
HEART RATE (beats/min.)	9	136	13	150	15
TIDAL VOLUME (liters/min.)	1-2	1.33	.30	1.40	.21
TIDAL VOLUME (liters/min.)	8-9	1.78	.38	1.96	.34
EXPIRED CO_2 (%)	8-9	4.14	.46	3.91	.43
VENTILATION (STPD) (liters/min.)	8-9	47.01	6.80	55.10	11.30
RESPIRATORY RATE (breaths/min.)	8-9	27	6	29	5
RESPIRATORY EXCHANGE RATIO	8-9	1.00	.05	1.05	.08
RATES OF CHANGE (per min.)					
1. Resp. Exchange Ratio		.02	.01	.03	.01
2. Respiratory Rate		.60	.47	.75	.56

TABLE 4

MEANS AND STANDARD DEVIATIONS OF ALL VARIABLES USED IN THE DEVELOPMENT OF THE MULTIPLE REGRESSION EQUATIONS FOR THE TWO TEST GROUPS

Variables	Time of Collection (Min.)	Active Group (N=15)		Inactive Group (N=13)	
		Mean	SD	Mean	SD
AGE (years)		28	6	29	8
FAT FREE WEIGHT (Kgs.)		65.15	5.79	64.21	5.45
HEART RATE (beats/min.)	9	130	9	152	11
TIDAL VOLUME (liters/min.)	1-2	1.29	.22	1.32	.37
TIDAL VOLUME (liters/min.)	8-9	2.11	.27	2.07	.31
CARBON DIOXIDE EXPIRED (%)	8-9	4.55	.63	4.01	.49
VENTILATION (STPD) (liters/min.)	8-9	47.11	7.83	52.55	11.16
RESPIRATORY RATE (breaths/min.)	8-9	27	7	27	6
RESPIRATORY EXCHANGE RATIO	8-9	.97	.12	1.02	.08
RATES OF CHANGE (per min.)					
1. Respiratory Exchange Ratio		.02	.01	.03	.01
2. Respiratory Rate		.58	.43	.72	.51

prediction group 0.68. The scatter diagrams and the correlation coefficients for the total prediction group, the active prediction group and the inactive prediction group are shown in Figures 1, 2, and 3 respectively.

In the process of developing the two equations for each of the prediction groups, zero order correlation coefficients among the independent variables were scanned before a variable was added to any multiple regression equation. The correlation coefficients for the variables used in developing the equations for the total prediction group are presented in Table 5. Similar correlation coefficients for the active prediction group are presented in Table 6 and for the inactive prediction group in Table 7.

Six multiple regression equations were developed. The three equations requiring gas analysis are presented in Table 8. The equations not requiring gas analysis are presented in Table 9. The order in which the variables were selected for each equation and the coefficients of determination at each stepwise stage for each equation are presented in Table 10. All multiple correlations are significant ($P < .01$). In any multiple regression equation the relative contribution of each variable can be compared in terms of standard coefficients (24). The relative contribution of each variable in each of the equations requiring gas analysis and those for the equations not requiring gas analysis are shown in Tables 11 and 12 respectively.

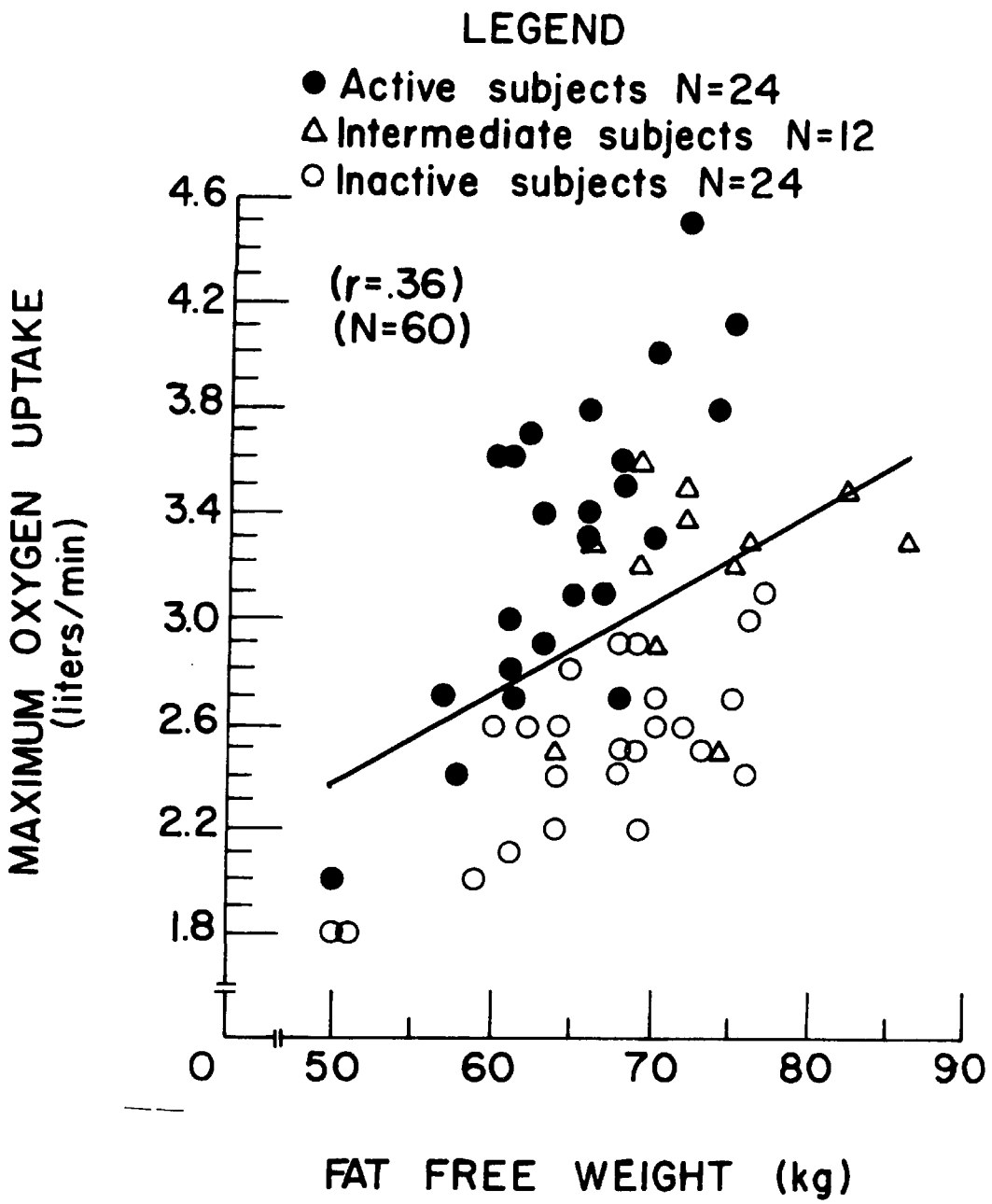


Fig. 1.--The relationship between fat free weight and maximum oxygen uptake for the total prediction group.

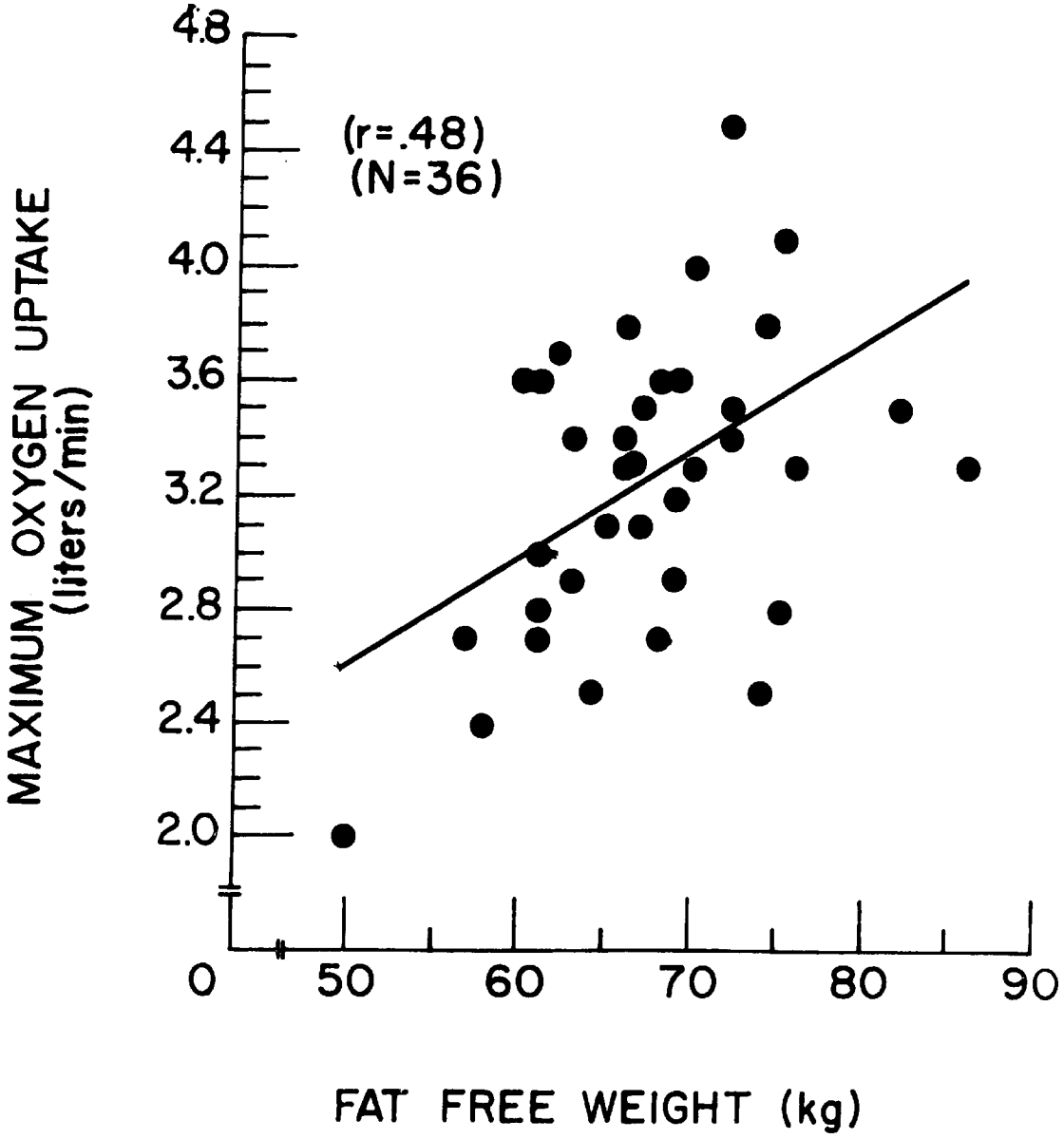


Fig. 2.—The relationship between fat free weight and maximum oxygen uptake for the active prediction group.

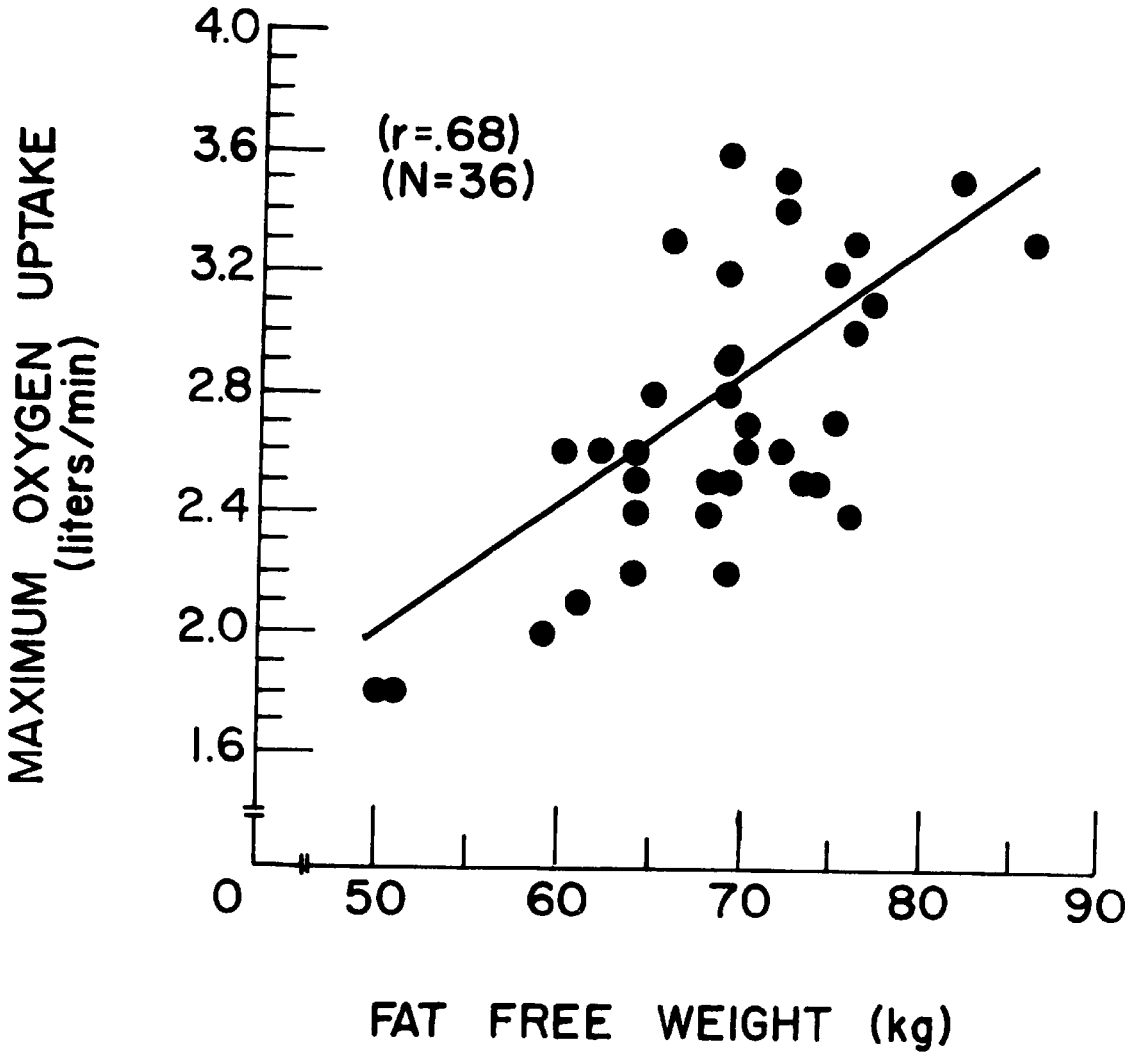


Fig. 3.--The relationship between fat free weight and maximum oxygen uptake for the inactive prediction group.

TABLE 5

INTERCORRELATION MATRIX FOR ALL VARIABLES USED IN THE DEVELOPMENT OF THE TWO MULTIPLE REGRESSION EQUATIONS FROM THE TOTAL PREDICTION GROUP (N=60)

Gas Analysis Required

	1.	2.	3.	4.	5.
1. AGE	1.00				
2. HEART RATE (8-9 min.)	.17	1.00			
3. EXPIRED CO_2 (8-9 min.)	-.33	-.34	1.00		
4. TIDAL VOLUME (1-2 min.)	-.06	.03	.17	1.00	
5. MAXIMUM OXYGEN UPTAKE	-.68	.36	.58	.33	1.00

Gas Analysis Not Required

	1.	2.	3.	4.	5.
1. AGE	1.00				
2. HEART RATE (8-9 min.)	.17	1.00			
3. Δ RESPIRATORY RATE	-.11	.56	1.00		
4. TIDAL VOLUME (1-2 min.)	-.06	.03	.01	1.00	
5. MAXIMUM OXYGEN UPTAKE	-.68	.36	-.34	.33	1.00

TABLE 6

INTERCORRELATION MATRIX FOR ALL VARIABLES USED IN THE DEVELOPMENT OF THE TWO MULTIPLE REGRESSION EQUATIONS FROM THE ACTIVE PREDICTION GROUP (N=36)

	Gas Analysis Required						
	1.	2.	3.	4.	5.	6.	7.
1. AGE	1.00						
2. FAT FREE WEIGHT	-.14	1.00					
3. HEART RATE (8-9 min.)	-.17	-.11	1.00				
4. EXPIRED CO_2 (8-9 min.)	-.27	.18	.08	1.00			
5. TIDAL VOLUME (1-2 min.)	.08	.14	.07	.19	1.00		
6. Δ RESP. EXCH. RATIO	.29	.21	.35	-.23	-.17	1.00	
7. MAXIMUM OXYGEN UPTAKE	-.62	.48	-.25	.45	.25	-.16	1.00

	Gas Analysis Not Required				
	1.	2.	3.	4.	5.
1. AGE	1.00				
2. FAT FREE WEIGHT	-.14	1.00			
3. HEART RATE (8-9 min.)	-.17	-.11	1.00		
4. TIDAL VOLUME (1-2 min.)	.08	.14	.07	1.00	
5. MAXIMUM OXYGEN UPTAKE	-.62	.48	-.25	.25	1.00

TABLE 7

INTERCORRELATION MATRIX FOR ALL VARIABLES USED IN THE DEVELOPMENT OF THE TWO MULTIPLE REGRESSION EQUATIONS FROM THE INACTIVE PREDICTION GROUP (N=36)

Gas Analysis Required

	1.	2.	3.	4.	5.
1. AGE	1.00				
2. FAT FREE WEIGHT	-.28	1.00			
3. RESP. EXCH. RATIO (8-9 min.)	.15	-.40	1.00		
4. TIDAL VOLUME (8-9 min.)	.34	.08	.00	1.00	
5. MAXIMUM OXYGEN UPTAKE	-.60	.68	-.47	-.06	1.00

Gas Analysis Not Required

	1.	2.	3.	4.	5.
1. AGE	1.00				
2. FAT FREE WEIGHT	-.28	1.00			
3. HEART RATE (8-9 min.)	.18	-.42	1.00		
4. RESPIRATORY RATE (8-9 min.)	.11	-.02	.31	1.00	
5. MAXIMUM OXYGEN UPTAKE	-.60	.68	-.61	-.29	1.00

TABLE 8

THREE MULTIPLE REGRESSION EQUATIONS
WHICH REQUIRE GAS ANALYSIS

TOTAL PREDICTION GROUP (N=60)

Max. $\dot{V}O_2$ = 4.5475 - .0285 X AGE - .0166 X HR9 + .2436 X $CO_2$9 + .6764 X VT2

ACTIVE PREDICTION GROUP (N=36)

Max. $\dot{V}O_2$ = 2.9660 - .0308 X AGE + .0259 X FFW - .0127 X HR9 + .2543 X $CO_2$9
+ .3303 X VT2 - 8.771 X ΔRQ

INACTIVE PREDICTION GROUP (N=36)

Max. $\dot{V}O_2$ = 3.6188 - .0220 X AGE + .0325 X FFW - 2.5874 X RQ9 + .2528 X VT9

CODES USED IN TABLE 8

AGE - Age as of test date (years)

FFW - Fat free weight (Kgs)

HR9 - Heart rate at 9 min. (beats/min.)

$CO_2$9 - % CO_2 expired 8-9 min.

RQ9 - Respiratory exchange ratio 8-9 min.

ΔRQ - Rate of change of respiratory exchange ratio (per min.)

VT2 - Tidal volume 1-2 min. (liters/min.)

VT9 - Tidal volume 8-9 min. (liters/min.)

Max. $\dot{V}O_2$ - maximum oxygen uptake (liters /min.)

TABLE 9

THREE MULTIPLE REGRESSION EQUATIONS
WHICH DO NOT REQUIRE GAS ANALYSIS

TOTAL PREDICTION GROUP (N=60)

Max. $\dot{V}O_2$ = 5.8836 - .0329 X AGE - .0177 X HR9 - .1746 X Δf + .7479 X VT2

ACTIVE PREDICTION GROUP (N=36)

Max. $\dot{V}O_2$ = 4.1744 - .0347 X AGE + .0231 X FFW - .0144 X HR9 + .4978 X VT2

INACTIVE PREDICTION GROUP (N=36)

Max. $\dot{V}O_2$ = 3.2235 - .0216 X AGE + .0290 X FFW - .0172 X f9 - .0073 X HR9

CODES USED IN TABLE 9

AGE - age as of test date (years)

FFW - fat free weight (kgs)

HR9 - heart rate at 9 min. (beats/min.)

Δf - rate of change of respiratory frequency (per min.)

f9 - respiratory rate 8-9 min. (breaths/min.)

VT2 - tidal volume 1-2 min. (liters/min.)

TABLE 10

COEFFICIENTS OF DETERMINATION (R^2) FOR THE SIX MULTIPLE REGRESSION EQUATIONS

Gas Analysis Required		Gas Analysis Not Required	
Variable	R^2	Variable	R^2
Total Prediction Equations			
AGE	0.47	AGE	0.47
HEART RATE (9 min.)	0.70	HEART RATE (8-9 min.)	0.70
TIDAL VOLUME (1-2 min.)	0.79	TIDAL VOLUME (1-2 min.)	0.79
EXPIRED CO_2 (8-9 min.)	0.83	Δ RESPIRATORY RATE	0.82
Active Prediction Equations			
AGE	0.38	AGE	0.38
FAT FREE WEIGHT	0.54	FAT FREE WEIGHT	0.54
HEART RATE (9 min.)	0.64	HEART RATE (9 min.)	0.64
TIDAL VOLUME (1-2 min.)	0.72	TIDAL VOLUME (1-2 min.)	0.72
EXPIRED CO_2 (8-9 min.)	0.76		
Δ RESP. EXCH. RATIO	0.79		
Inactive Prediction Equations			
FAT FREE WEIGHT	0.46	FAT FREE WEIGHT	0.46
AGE	0.64	AGE	0.64
RESP. EXCH. RATIO (8-9 min.)	0.77	HEART RATE (9 min.)	0.75
TIDAL VOLUME (8-9 min.)	0.80	RESPIRATORY RATE (8-9 min.)	0.78

TABLE 11

STANDARD COEFFICIENTS FOR THREE EQUATIONS REQUIRING GAS ANALYSIS

Total Prediction Equation	
AGE	0.52
HEART RATE (8-9 min.)	0.44
TIDAL VOLUME (1-2 min.)	0.27
EXPIRED CO_2 (8-9 min.)	0.21
Active Prediction Equation	
AGE	0.59
FAT FREE WEIGHT	0.35
HEART RATE (9 min.)	0.31
TIDAL VOLUME (1-2 min.)	0.19
EXPIRED CO_2 (8-9 min.)	0.22
Δ RESP. EXCH. RATIO	0.19
Inactive Prediction Equation	
FAT FREE WEIGHT	0.50
AGE	0.46
RESP. EXCH. RATIO (8-9 min.)	0.42
TIDAL VOLUME (8-9 min.)	0.18

TABLE 12

STANDARD COEFFICIENTS FOR THREE EQUATIONS
NOT REQUIRING GAS ANALYSIS

Total Prediction Equation	
AGE	0.60
HEART RATE (9 min.)	0.47
TIDAL VOLUME (1-2 min.)	0.30
Δ RESPIRATORY RATE	0.15
Active Prediction Equation	
AGE	0.66
FAT FREE WEIGHT	0.31
HEART RATE (9 min.)	0.35
TIDAL VOLUME (1-2 min.)	0.29
Inactive Prediction Equation	
AGE	0.45
FAT FREE WEIGHT	0.45
HEART RATE (9 min.)	0.24
RESPIRATORY RATE (8-9 min.)	0.20

Validity and Reproducibility of Prediction

The validity of the six prediction equations was evaluated by calculating the predicted maximum oxygen uptakes of the test groups (N=28). The data of the total test group were used in the two equations developed on the basis of the total prediction group. The correlations between the predicted and the observed maximum oxygen uptakes for the equation requiring gas analysis was 0.56, and for the equation not requiring gas analysis was 0.51 (Figures 4 and 5).

Data from the active test group (N=15) was used to evaluate the two active prediction equations. The scattergrams and correlation coefficients for the active test group predicted by using the two active prediction equations are shown in Figures 6 and 7. Similarly the results of the inactive test group predicted by the inactive prediction equations are presented in Figures 8 and 9.

In order to evaluate the use of "habitual physical activity" as a variable, the predicted to observed maximum oxygen uptake data for the active test group and for the inactive test group were combined. Figure 10 presents the data for the equations requiring gas analysis and Figure 11 presents the data for the equations which did not require gas analysis. The observed to predicted maximum oxygen uptake results were compared to similar data calculated on the basis of the total prediction group equation. Means, standard deviations, correlation coefficients, mean differences, standard deviations of the

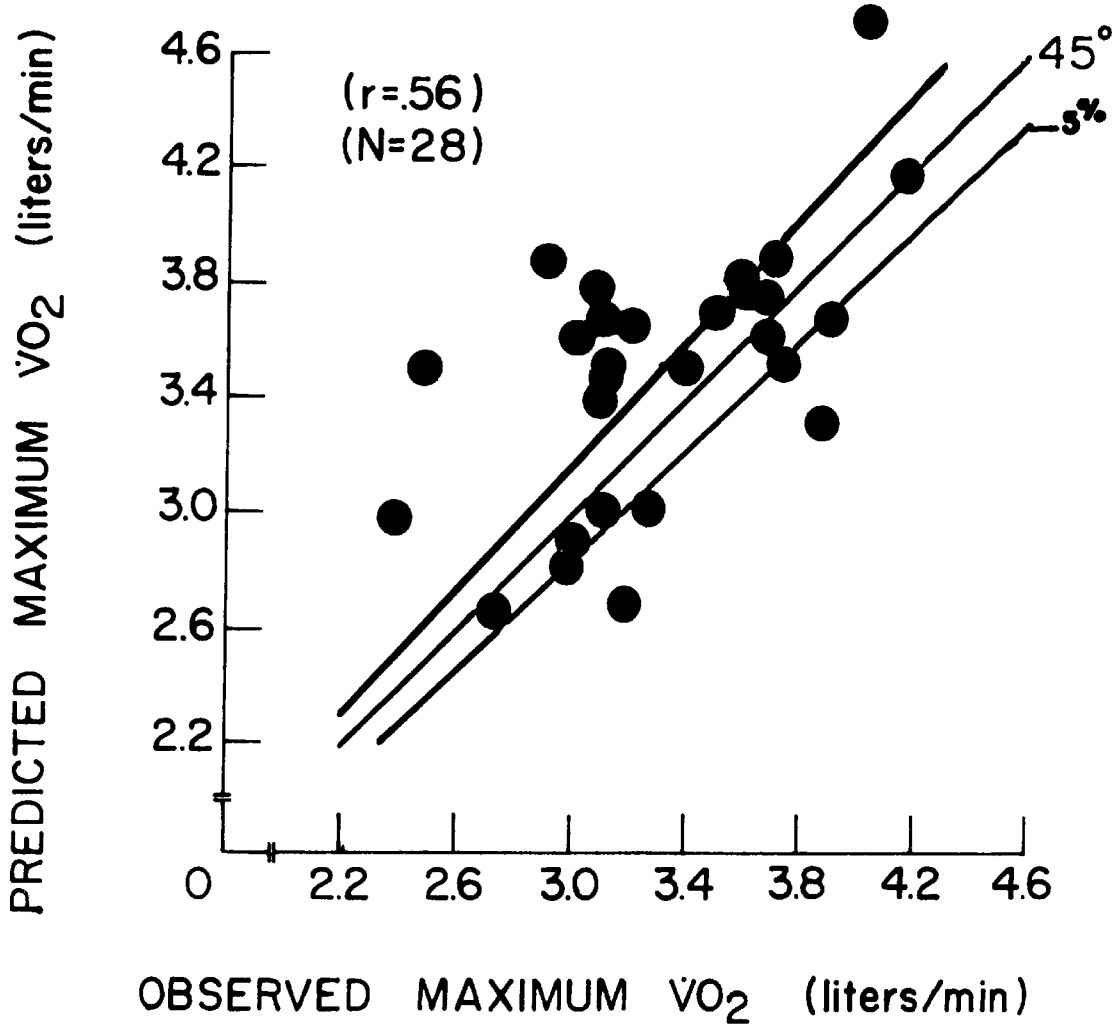


Fig. 4.--Comparison between predicted and observed maximum oxygen uptake for the total test group using the total prediction group equation which required gas analysis.

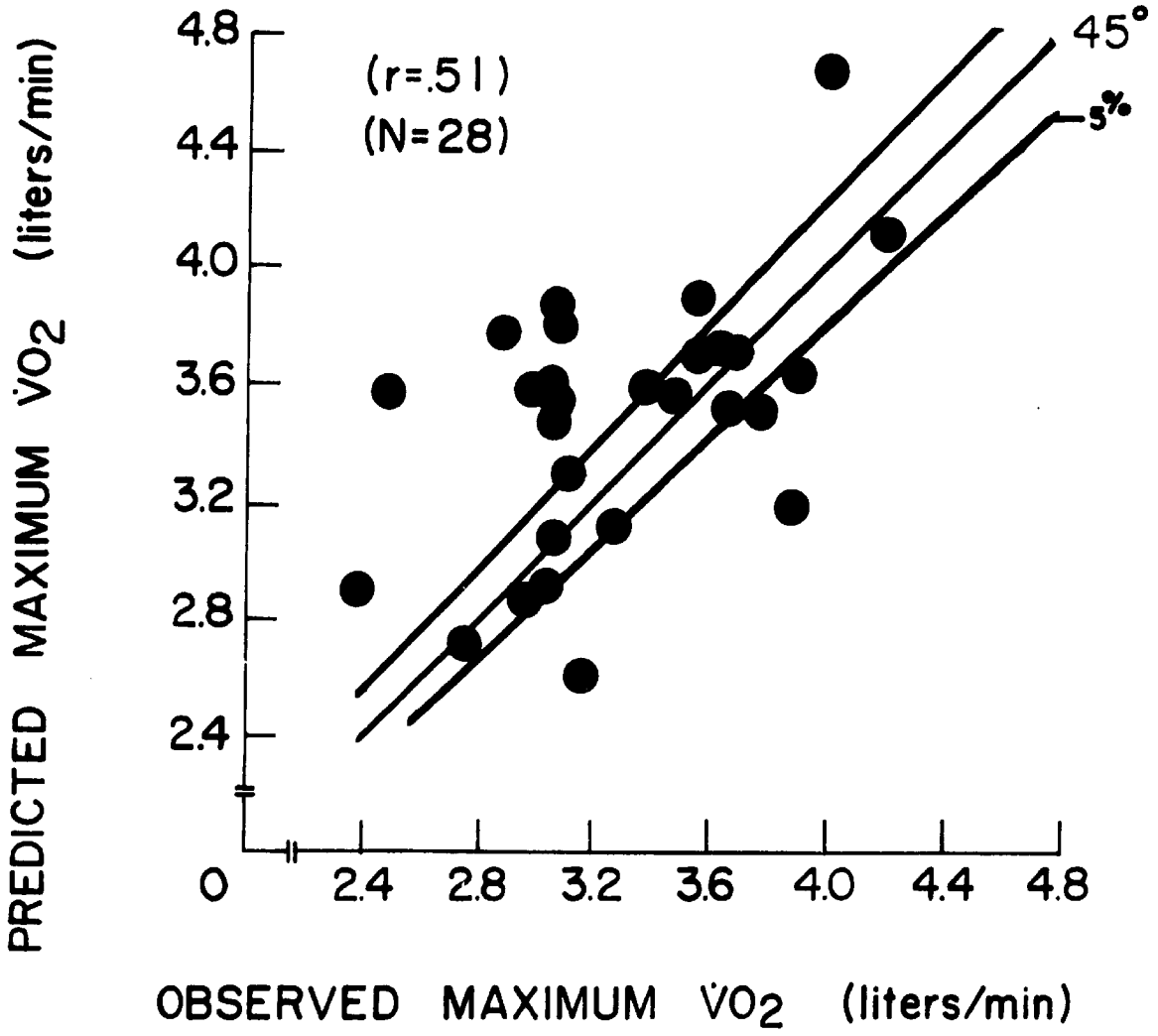


Fig. 5.--Comparison between observed and predicted maximum oxygen uptake for the total test group using the total prediction group equation which did not require gas analysis.

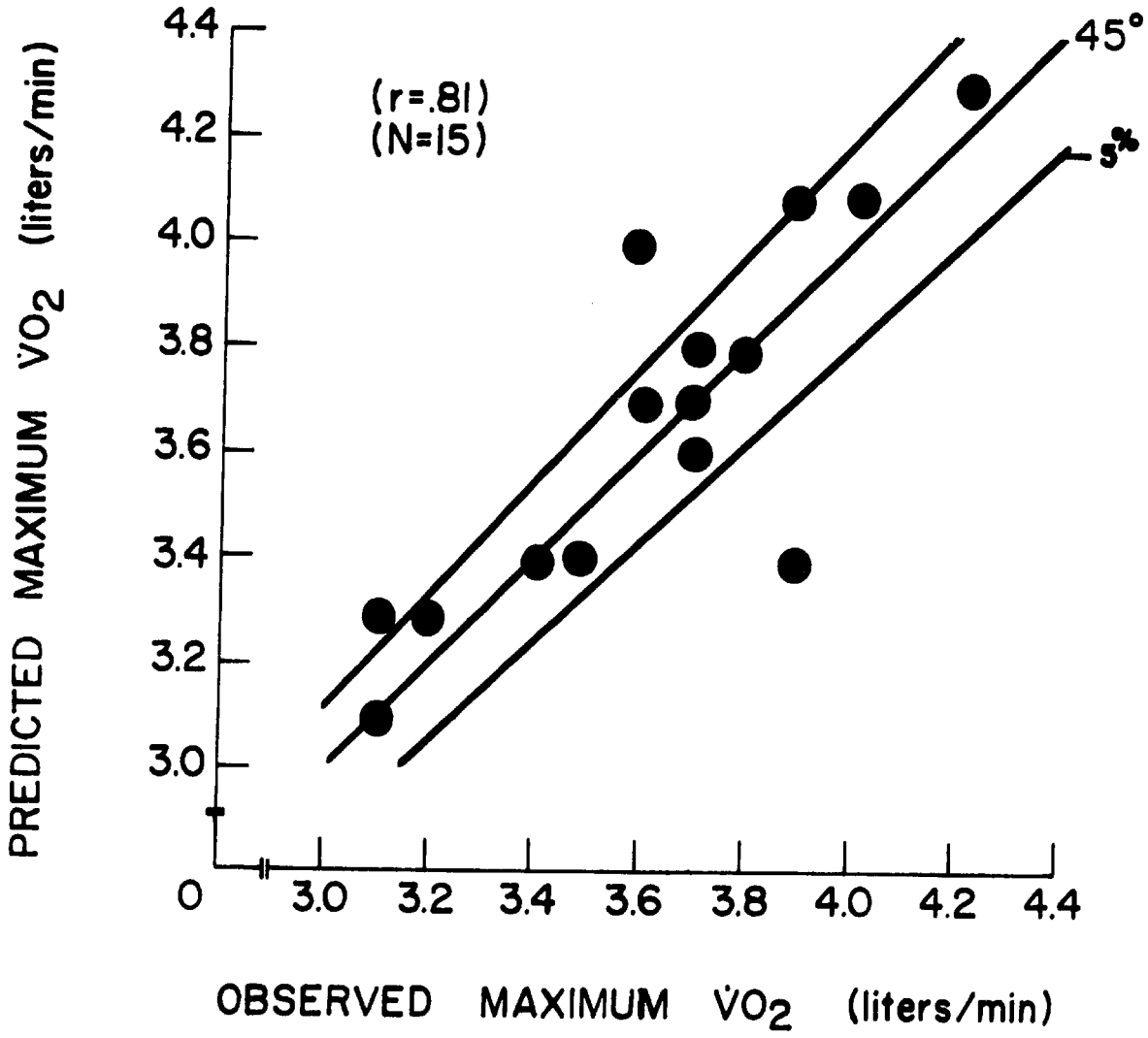


Fig. 6.--Comparison between observed and predicted maximum oxygen uptakes for the active test group using the active prediction equation which required gas analysis.

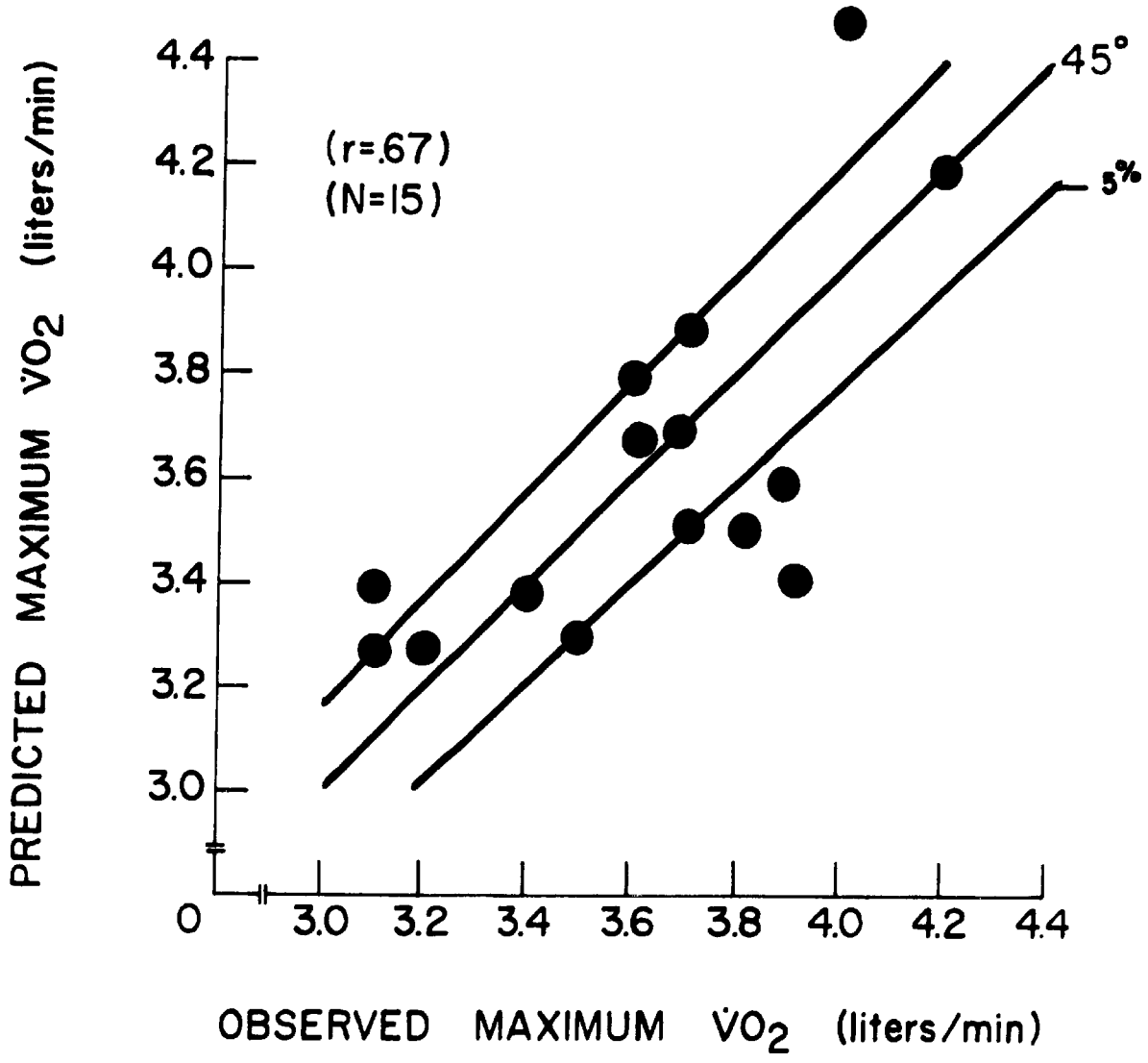


Fig. 7.--Comparison between observed and predicted maximum oxygen uptakes for the active test group using the active prediction equation which did not require gas analysis.

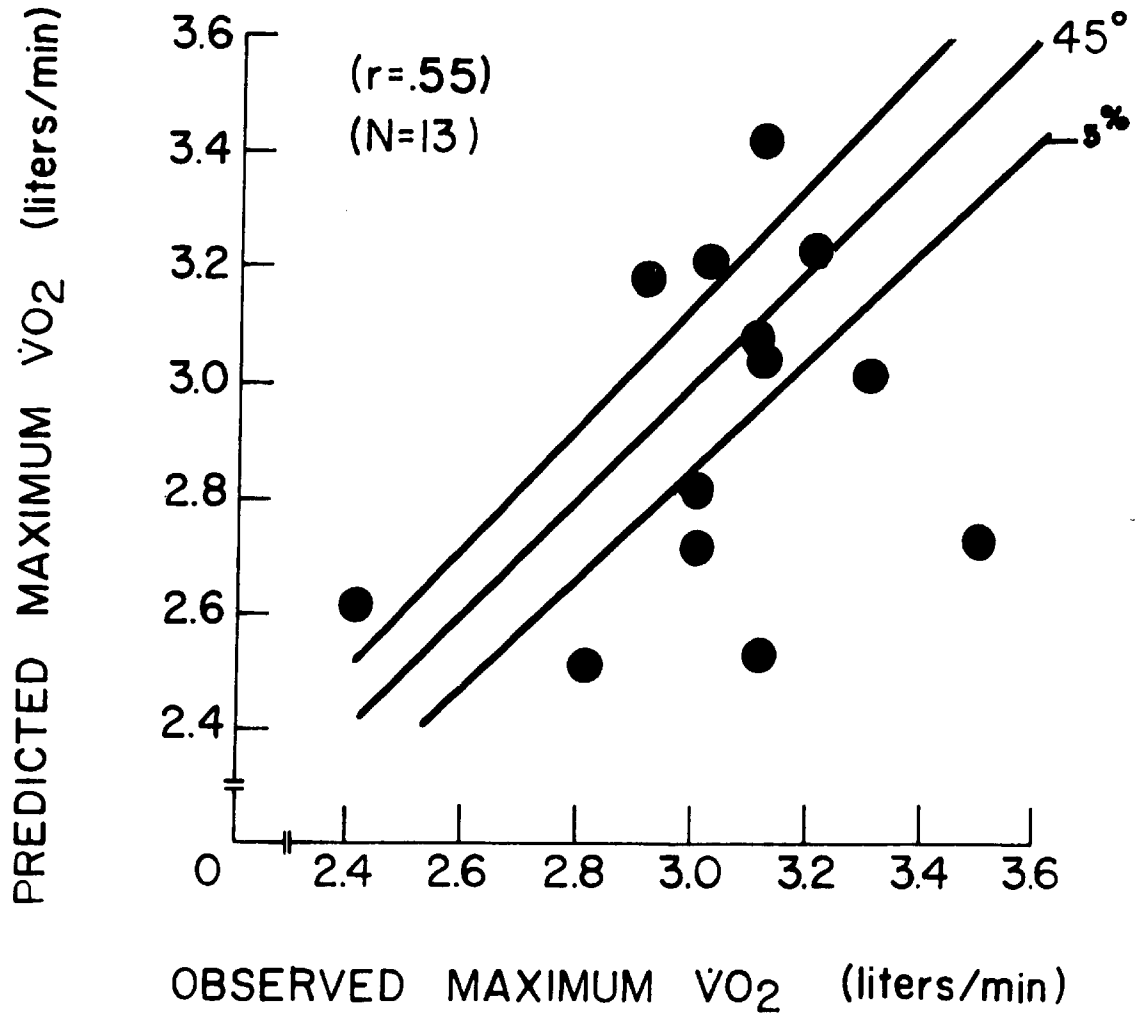


Fig. 8.--Comparison between observed and predicted maximum oxygen uptakes for the inactive test group using the inactive prediction equation which does not require gas analysis.

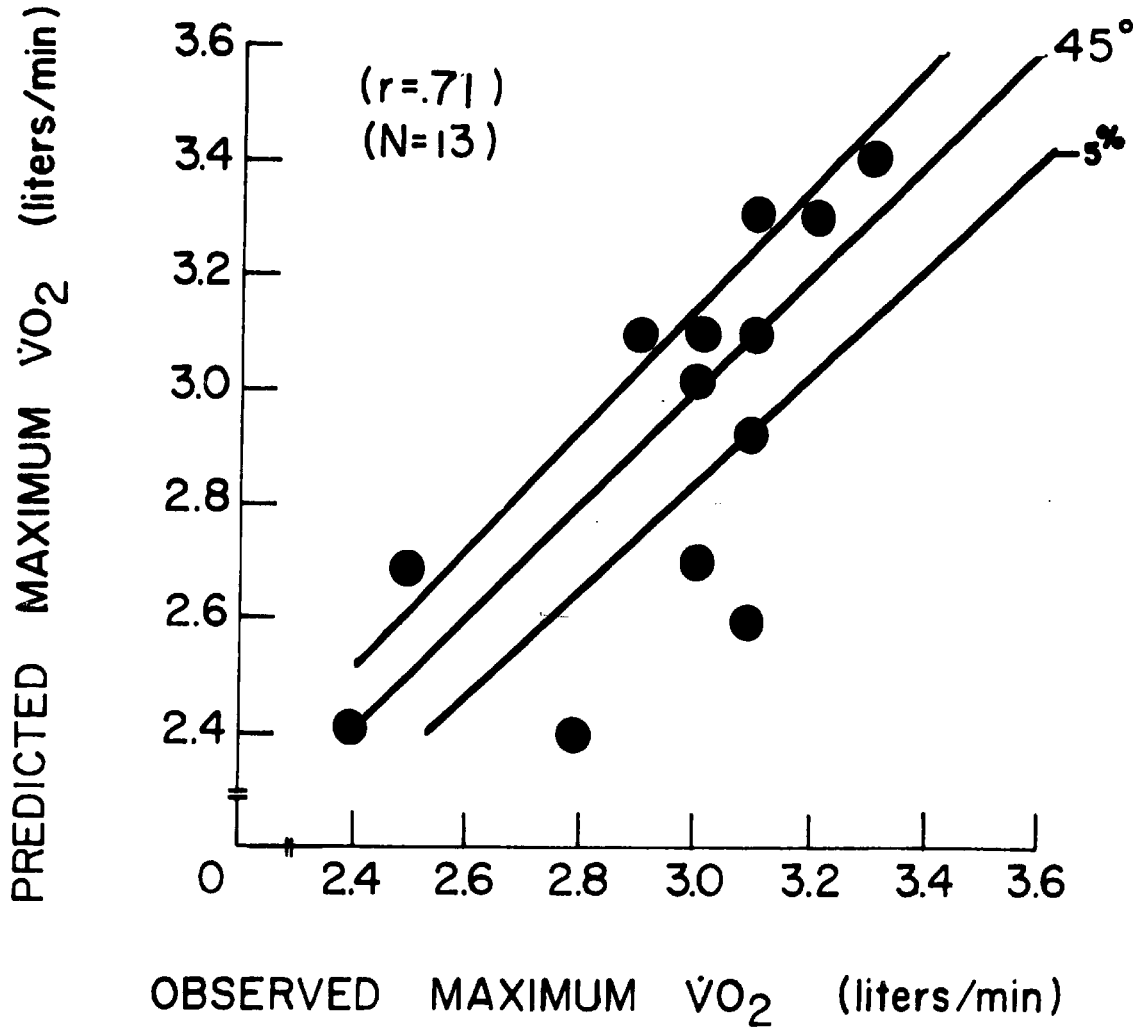


Fig. 9.--Comparison between observed and predicted maximum oxygen uptakes for the inactive test group using the inactive prediction equation which required gas analysis.

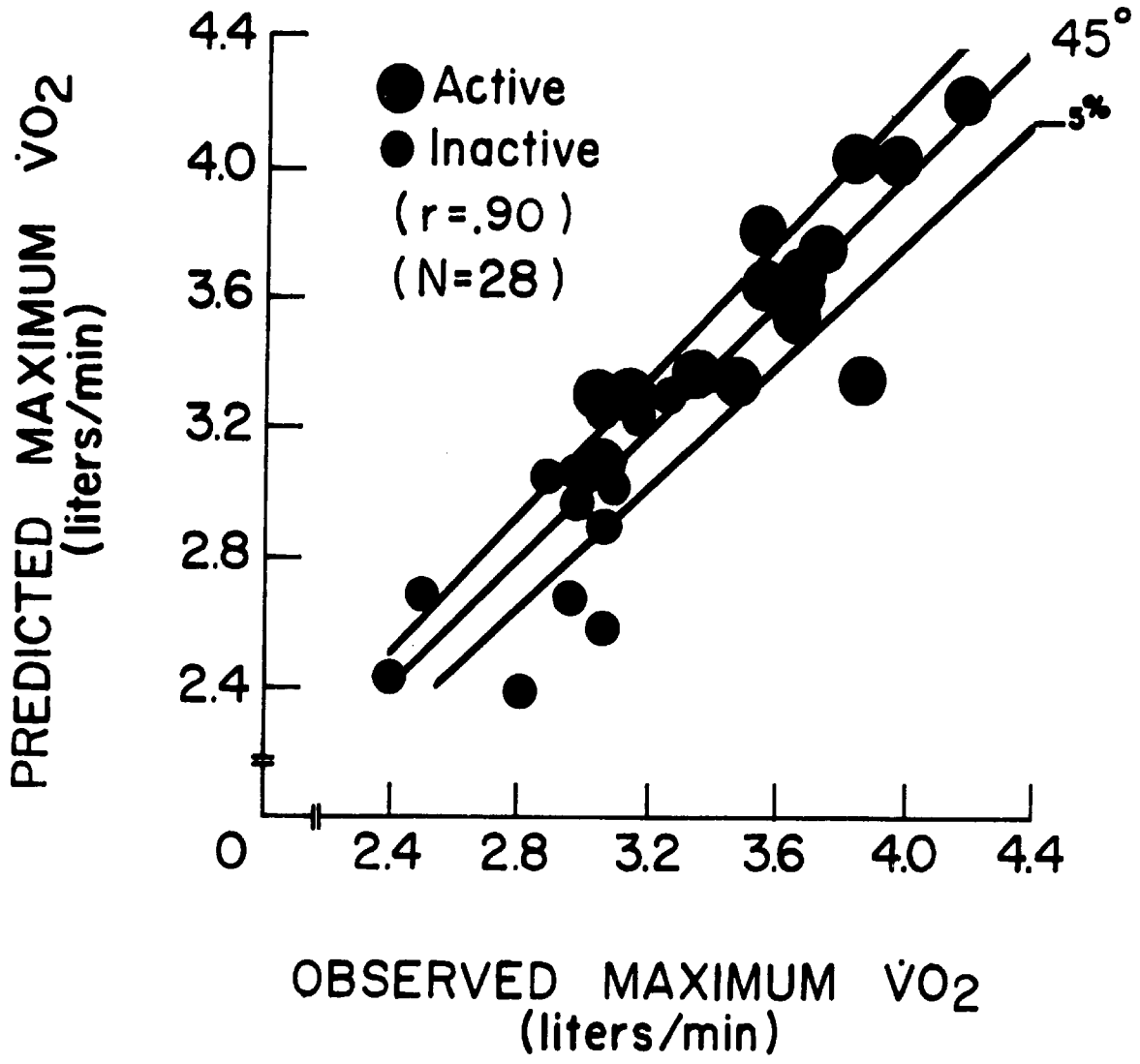


Fig. 10.--Comparison between observed and predicted maximum oxygen uptake for the total test group using the appropriate activity related equation which requires gas analysis.

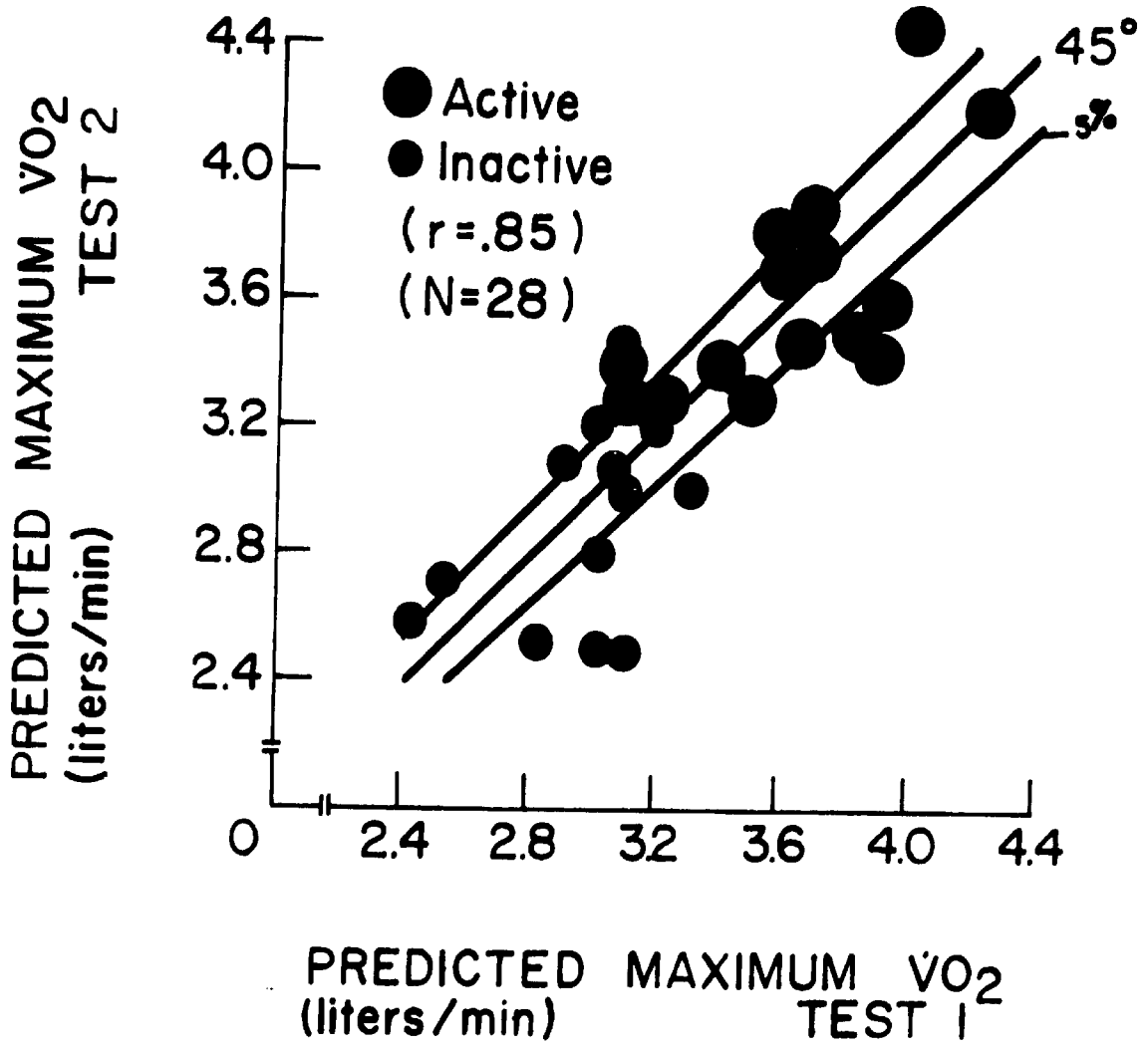


Fig. 11.--Comparison between observed and predicted maximum oxygen uptake for the total test group using the appropriate activity related equation which does not require gas analysis.

differences and paired "t" test results showing the relationship between each of the predicted and observed maximum oxygen uptakes for the test groups are presented in Table 13. Only the paired "t" test between the observed maximum oxygen uptake and the prediction equation based on the total prediction group which required gas analysis was significantly different ($P < .05$).

The results of the test-retest data on twelve subjects of the test sample are shown in Figure 12. The correlation between the two predicted oxygen uptakes is highly significant ($r=0.91$). The paired "t" test was not significant ($P < .01$).

TABLE 13

MEANS, STANDARD DEVIATIONS, MEAN DIFFERENCES, STANDARD DEVIATION OF THE DIFFERENCES, CORRELATION COEFFICIENTS, AND PAIRED "t" RESULTS FOR THE PREDICTION OF MAXIMUM OXYGEN UPTAKE (LITERS/MIN.)

Equation Used	Number Evaluated (N)	Mean	SD	Mean (Diff.)	SD (Diff.)	r*	t
			Gas Analysis Required				
TOTAL PREDICTION	28	3.50	.46	-.18	.42	.56	-2.312**
ACTIVE PREDICTION	15	3.67	.35	-.04	.21	.81	-.776
INACTIVE PREDICTION	13	2.92	.33	.04	.23	.71	.647
TOTAL COMPOSITE PREDICTION	28	3.32	.50	.00	.22	.90	-.061
			Gas Analysis Not Required				
TOTAL PREDICTION	28	3.48	.45	-.17	.44	.51	-1.996
ACTIVE PREDICTION	15	3.63	.34	.00	.27	.67	.006
INACTIVE PREDICTION	13	2.89	.30	.07	.26	.55	.985
TOTAL COMPOSITE PREDICTION	28	3.27	.47	.03	.26	.84	.676

* All correlation coefficients significantly different from zero ($P < .05$).

** $t_{0.05} > 2.052$

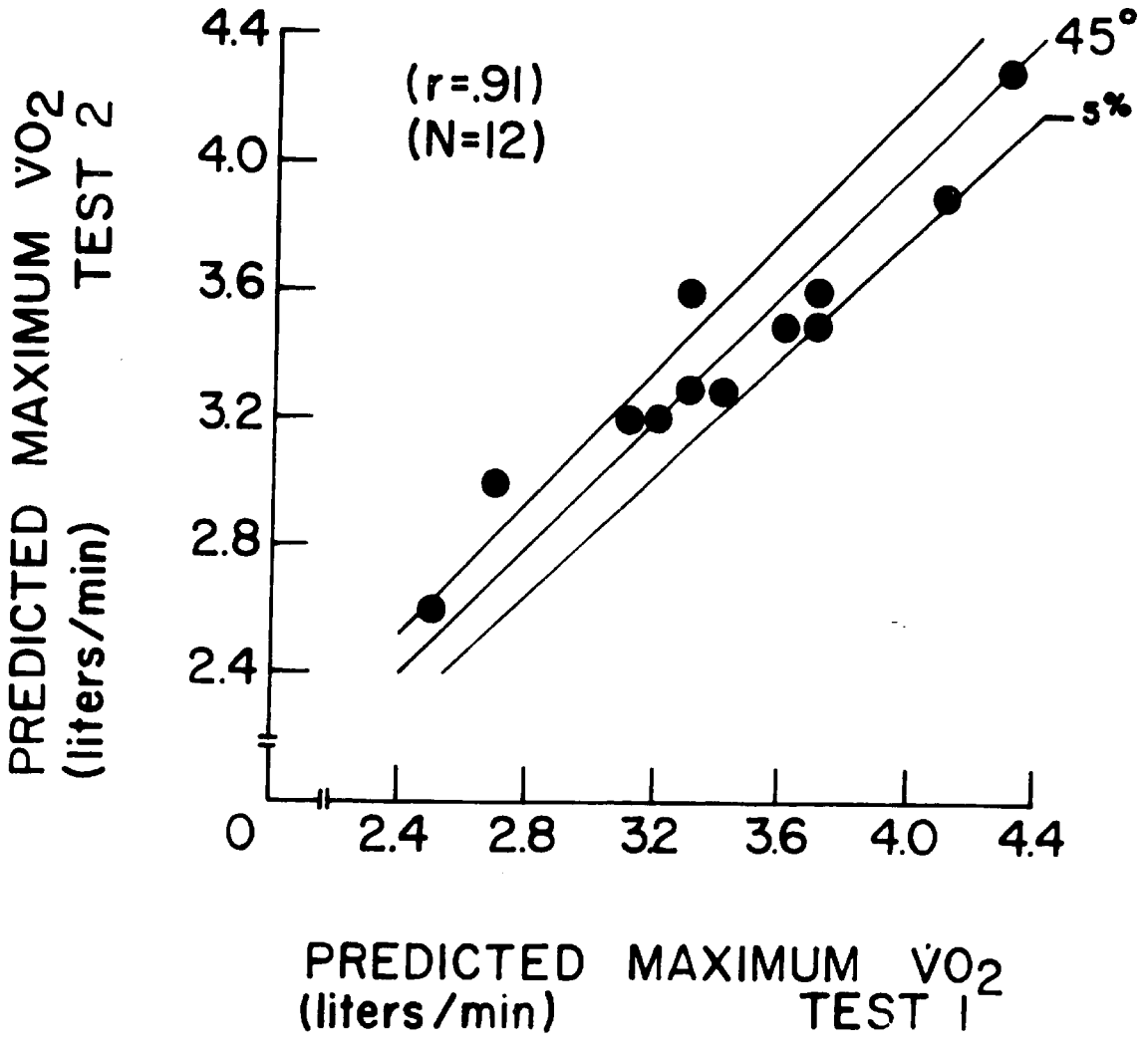


Fig. 12.--Reproducibility of predicted maximum oxygen uptake (liters/min.).

CHAPTER IV

DISCUSSION

Maximum oxygen uptakes can be predicted with reasonable precision (r=0.90) from submaximal treadmill test data by multiple regression equations. The factors which contribute to an effective prediction of maximum oxygen uptake are: age, fat free weight, habitual level of physical activity, cardiovascular and respiratory response to submaximum work. The statistical technique of stepwise multiple regression can be used to organize these relatively independent factors into an effective multivariate equation for the prediction of maximum oxygen uptake.

Age is the single best predictor in all six multiple regression equations in this study. A negative relationship between age and maximum oxygen uptake has been reported by Robinson (46), Astrand (2), and Von Dobeln et al. (62). This pattern is also evidenced in the present study (Table 14). Balke (11) and Faulkner et al. (26) have both observed that the decline in maximum oxygen uptake with increasing age is less in physically active as compared to physically inactive men.

Taylor (56) has reported that during a submaximum treadmill walk submaximal oxygen uptake can be accurately predicted from body weight, grade, and speed. Many

TABLE 14

AGE RELATED MAXIMUM OXYGEN UPTAKES
MEASURED IN LITERS PER MINUTE

	Age In Years			
	20-29	30-39	40-49	50+
Present study	3.40 (N=20)	3.11 (N=10)	2.60 (N=17)	2.41 (N=13)
Robinson (46)	3.53 (N=11)	3.42 (N=10)	2.92 (N=10)	2.63 (N=9)
Astrand (2)	4.19 (N=25)	3.01 (N=17)	2.99 (N=9)	2.54 (N=66)
Von Dobeln et al. (62)	----	3.17 (N=21)	2.72 (N=21)	2.54 (N=22)

investigators (16, 43, 61, 65) have reported a higher correlation between fat free weight and maximum oxygen uptake than between body weight and maximum oxygen uptake. The published correlations between fat free weight and maximum oxygen uptake range from 0.13 (29) to 0.85 (43) and for body weight from 0.05 (29) to 0.75 (43). The variability is largely due to the type of sample used. Correlation coefficients were calculated for the total group, the active group, and the inactive group in a paper published by Hermansen and Andersen (29). The correlation coefficients in the present study are slightly higher than these in each of the six groupings (Table 15). The lower correlation coefficients (Table 15) between maximum oxygen uptake and fat free weight for the total groups in both studies may be partially explained by a lower intercept and a different slope between maximum oxygen uptake and weight for the inactive groups than for the active groups. Thus both the maximum oxygen uptake and the fat free weight of a subject are also partially related to his habitual physical activity.

Balke and Ware (11), Faulkner et al. (26), and Keys et al. (37), have reported a negative relationship between age and physical activity. Although habitual physical activity and maximum oxygen uptake are both inversely related to age, the exact interrelationships have not been delineated. In the prediction of maximum oxygen uptake the relative contributions of age and habitual physical activity cannot be partialled out because a quantitative measure of

TABLE 15

CORRELATION COEFFICIENTS BETWEEN BODY WEIGHT (kgs) AND MAXIMUM OXYGEN UPTAKE (liters/min) AND BETWEEN FAT FREE WEIGHT (kgs) AND MAXIMUM OXYGEN UPTAKE (liters/min) FOR PHYSICAL ACTIVITY GROUPS

Activity Group	Present Study			Andersen Hermansen (1)		
	Fat Free		Body Weight	Fat Free		Body Weight
	N	r	r	N	r	r
Total group	60	0.36	0.17	97	0.13	0.05
Active group	36	0.48	0.38	60	0.26	0.20
Inactive group	36	0.68	0.61	37	0.50	0.46

habitual physical activity is not available. Habitual physical activity has a significant influence on the intercept and slope of a number of physiological responses to submaximum work. Since habitual physical activity is an important factor in the prediction of maximum oxygen uptake that cannot be treated statistically by regression analysis, an arbitrary classification into physically active and physically inactive groups was necessary. The success of this division is evidenced by the much improved correlation coefficient of 0.90 between the observed maximum oxygen uptake and the prediction equations developed from physically active and physically inactive groups as compared to the 0.56 correlation between the observed maximum oxygen uptake and the prediction equations for the total group. The mean absolute difference was much greater for the prediction based on the total group data (361 ml) than for the prediction based on the active and inactive groups (168 ml). In addition only the paired "t" ratio between the observed maximum oxygen uptake and the prediction equation developed from the total prediction group was significant at the .05 level.

The need for physical activity classifications was further substantiated by data on two highly trained athletes (Max $\dot{V}O_2 > 60$ ml/kg per min). The maximum oxygen uptakes estimated from the active prediction equation of both subjects was more than 750 ml/min less than the observed maximum oxygen uptakes. A third physical activity classification

appears necessary to predict maximum oxygen uptakes of highly trained men. These data support the development of an extremely active group as suggested by Keys et al. (37).

Different test administrators are likely to have different interpretations as to what constitutes a physically active or physically inactive subject. A clinician who deals with older and often sick patients will have a different frame of reference for his classification than would an investigator who deals with more active pathology free young adults. Twelve subjects with the highest habitual physical activity level were selected from the inactive group and their data were used in both the active and the inactive prediction groups. Habitual physical activity is in reality a continuum and this interlocking procedure was designed to ease the transition from one descrete group to the other.

To determine the effect of errors in classification on the prediction of maximum oxygen uptake the maximum oxygen uptakes of the four most active of the inactive test group subjects were predicted from both the active and inactive prediction equations (Table 16). From this comparison it appears that errors in classification would not have been too serious. There is some suggestion that these four subjects might better have been classified as actives rather than inactives. This suggestion may be due to the differences between the prediction and test group. The inactive test group was more active, younger, and weighed less than

TABLE 16

COMPARISON BETWEEN OBSERVED AND PREDICTED MAXIMUM OXYGEN UPTAKES (liters/min) BY BOTH THE ACTIVE AND INACTIVE EQUATIONS FOR THE INACTIVE TEST GROUP SUBJECTS (highest physical activity)

Subject ID	Predicted Max. $\dot{V}O_2$				
	Observed Max. $\dot{V}O_2$	Active Equation	Diff.	Inactive Equation	Diff.
3101	3.058	2.905	-.152	2.561	-.496
3102	2.965	2.736	-.228	2.723	-.241
3104	2.776	2.628	-.147	2.378	-.397
3106	3.049	3.007	-.041	2.976	-.072

the inactive prediction group.

In large epidemiological studies technicians and specialized equipment are available. However, because of the dangers inherent in exercising diverse populations maximally, on many occasions it may be advisable to estimate maximum oxygen uptake. Therefore regression equations were constructed which utilized variables which required gas analysis. In clinical, school, and other field test situations the prediction of maximum oxygen uptake is limited by technical personnel and equipment. Therefore, a second set of equations incorporated variables which did not require the equipment necessary to analyze respiratory gases.

All published studies (6, 36, 39, 62) on the accuracy of prediction equations of maximum oxygen uptake are based on the data actually used to develop the prediction equations. This investigation is the first to include a test sample, for evaluation purposes, whose data were not used in the development of the prediction equation. In order to make a comparison with the published data it was necessary to calculate the predicted maximum oxygen uptakes of the sixty subjects whose data were used to construct the prediction equations. The present study showed a similar mean difference between the observed and predicted maximum oxygen uptakes compared to the published prediction data. The standard deviation of the difference was also within the range of the published data (Table 17).

The data on the test sample of this study can be

TABLE 17

COMPARISON AMONG AVAILABLE METHODS FOR PREDICTING MAXIMUM OXYGEN UPTAKES FROM SUBMAXIMUM WORK LOADS

Equation	Mean Difference (ml)	Standard Deviation (Diff. in ml)
Present study*	040	222
Astrand & Ryhming (6)	109	323
Maritz et al. (39)	260	510
Issekutz et al. (36)	002	089
Von Dobeln et al. (62)	000	240

* Appropriate activity related equations requiring gas analysis.

compared to the data in the study of Glassford et al. (28). These investigators used the data of twenty-three subjects on two maximum treadmill tests, a maximum ergometer test, and the Astrand Ryhming prediction nomogram in a comparison study (Table 18). The deviation between the predicted and observed maximum oxygen uptakes was less in the present study than in the study by Glassford et al. (28) that used the Astrand and Ryhming nomogram. The correlation coefficient of 0.90 also indicates a closer relationship between the predicted and observed maximum oxygen uptakes in this study than that obtained from the nomogram (r=0.75).

No data has been reported on the reproducibility of data obtained from prediction equations. The reproducibility of estimates of maximum oxygen uptake by multiple regression predictions (r=0.91) is as good as the reproducibility of actual observations of maximum oxygen uptakes (r=0.91 to 0.95) (38, 44).

The most frequently used variables in the multiple regression equations were: age, fat free weight, and a submaximal heart rate of 143 $\pm$ 18 beats per minute. Various measures of ventilation occurred less frequently. In terms of standard coefficients (24) the variables which contributed most to the prediction of maximum oxygen uptake in the activity related equations were: age, and fat free weight. The standard coefficients ranged from 0.45 to 0.66 for age and from 0.31 to 0.47 for fat free weight. The age decrement calculated from the six regression equations ranged from

TABLE 18

COMPARISON BETWEEN THE PRESENT STUDY AND THE ASTRAND AND RYHMING NOMOGRAM (28) WHEN ESTIMATIONS OF MAXIMUM OXYGEN UPTAKES (liters/min) ARE MADE FROM SUBJECTS WHOSE DATA WERE NOT USED TO DEVELOP THE PREDICTION EQUATIONS

Equation	Predicted Mean	Actual Mean	SD (Diff.)	r
Astrand & Ryhming*	3.71	3.75	0.48	0.75
Present Study Activity Related Equations	3.32	3.31	0.24	0.90

* From Glassford et al. (28).

0.26 to 0.36 liters/min. per each ten year age span. Data published by Von Dobeln et al. (62) and Astrand (2) indicated an age decrement of approximately 0.30 liters/min. per each ten year age span.

The total prediction equations do not include fat free weight as a prediction variable because of the low correlation between fat free weight and maximum oxygen uptake in the total prediction group (r=0.36) as compared to 0.48 for the active group and 0.68 for the inactive groups. Fat free weight would have been the next stepwise addition to the total prediction equation. Since this addition contributed less than 2% to the multiple coefficient of determination fat free weight was not added to the equation.

Respiratory frequency and tidal volume were less effective than weight as predictors in the activity related equations. They became more effective in terms of standard coefficients and therefore replaced weight in the total prediction equations. These ventilation variables tend to be less reliable as predictors than is the fat free weight of homogeneous activity groups. A subject unaccustomed to walking on the treadmill will often breath more rapidly than a person who is accustomed to treadmill walking. This more rapid respiratory frequency is accompanied by a lower tidal volume regardless of the level of fitness of the subject. The replacement of the partial regression coefficient of fat free weight by the less reliable respiratory terms seems to be a major reason why the total prediction equations are

not as accurate as the equations based on the data from the two physical activity groups.

In all multiple regression equations a negative relationship was apparent between submaximum heart rate and maximum oxygen uptake. The data of this study support the concept that a discrete heart rate of approximately 140 beats/min. is as good a predictor as heart rate slope. The multiple correlation coefficient for age, fat free weight, and submaximum heart rate to maximum oxygen uptake ($R > 0.79$) is approximately the same as the correlation coefficient between predicted and observed maximum oxygen uptakes ($r=0.80$) as reported by Astrand (2).

For a given submaximum oxygen uptake an inactive subject has a higher heart rate and higher respiratory exchange ratio than an active subject. The higher values result, because for an inactive subject a given submaximum oxygen uptake constitutes a greater percentage of maximum oxygen uptake than it does for the active subject. Therefore, both heart rate and respiratory exchange ratio are measures of a similar type of physiologic strain. The inclusion of one of these variables tends to statistically eliminate the other. The correlation between heart rate and the respiratory exchange ratio for the inactive prediction group was 0.65. Support for this interpretation is also evidenced in Astrand's use of submaximal heart rate (2), and Issekutz et al. (36) use of the respiratory exchange ratio in prediction equations. The mean respiratory

exchange ratio of 1.05 ± 0.08 for the inactive prediction group was higher than the respiratory exchange ratio for the active prediction group (1.00 ± 0.05). Issekutz et al. (35) reported that the most accurate prediction of maximum oxygen uptake occurred as the respiratory exchange ratio approached 1.10. The respiratory exchange ratio might have entered the prediction equation for the physically inactive group in preference to the heart rate because it was approaching the level necessary for predictive purposes. In terms of multiple coefficients of determination the addition of the respiratory exchange ratio increased the coefficient of determination to 0.77 while the heart rate increased the coefficient of determination to 0.75.

The response of the active subject to exercise differs from that of the inactive subject both quantitatively and qualitatively. The more active subject has a higher percentage of carbon dioxide, extracts a higher percentage of oxygen, ventilates less, and has a lower respiratory exchange ratio than does the inactive subject. From the results of this study it appears that the percentage of carbon dioxide expired is slightly better as a predictor of maximum oxygen uptake than is the percentage of oxygen extracted. As a result, the percentage of carbon dioxide expired was incorporated as a partial regression term. The correlation between the percentage of carbon dioxide expired and the per cent of oxygen extracted is greater than 0.89 for all prediction groups. Statistically this excluded

the per cent oxygen extracted. The slightly higher coefficient of determination indicated that the per cent oxygen extracted could have been added in place of the per cent carbon dioxide expired without significantly altering the results of the prediction equations.

In general the prediction of maximum oxygen uptake by a multiple regression equation must account for age, habitual level of activity, fat free weight, proportion of maximum physiologic strain, respiratory function, and the percentage of carbon dioxide expired. The technique of multiple regression allows the inclusion of more determinants of maximum oxygen uptake than do published prediction equations (6, 36, 39, 62). It appears that the inclusion of respiratory efficiency, per cent carbon dioxide expired and a physical activity classification are necessary for a reasonably accurate prediction of maximum oxygen uptake from submaximum test data.

CHAPTER V

SUMMARY AND CONCLUSIONS

Sixty male subjects between the ages of twenty and sixty-two years were used to develop two sets of multiple regression equations for the prediction of maximum oxygen uptake from a progressive treadmill walk (26). Twenty-five variables from the 1 to 2 minute and 8 to 9 minute time periods were used as possible predictors of maximum oxygen uptake. The technique used to develop the multiple regression equation was one of stepwise selection of the independent variable which contributed the most to the multiple coefficient of determination at each stage of construction. The regression equation additions were stopped when the next stepwise addition increased the multiple coefficient of determination less than two per cent. This procedure was validated by an established stepwise regression programme (58) which included or excluded terms on the basis of significant F ratios.

The sixty subjects were divided into two interlocking groups each having thirty-six subjects. Any subject who participated in regular physical activity two or more times per week during the past six months was classified as active. Subjects who participated less than this were classified as inactive. Twelve subjects from the

inactive group with the highest habitual physical activity were also included in the active prediction group in order to ease the transition between the two activity groups.

Two equations based on the total prediction sample were developed. One of these equations required gas analysis; the other did not require gas analysis. Four activity related equations were also constructed: active and inactive prediction equations that required gas analysis, and active and inactive prediction equations that did not require gas analysis.

Data on twenty-eight men were used to evaluate the accuracy of the predictions of maximum oxygen uptake. The test sample subjects were preclassified according to the activity criteria. There were fifteen active subjects and thirteen inactive subjects. Twelve of the test sample were retested on the submaximal treadmill test to check the reproducibility of the prediction of maximum oxygen uptake by multiple regression equations.

The validity and reproducibility of the prediction equations were assessed by correlation coefficients and paired "t" analysis.

From this study the following conclusions are warranted.

1. Multiple regression equations can be used to predict maximum oxygen uptake with reasonable accuracy from submaximum treadmill test data if the physical activity of the subjects is accounted for by preclassifying them as either active or inactive.

2. Multiple regression equations based on discrete habitual physical activity classification provide a more accurate prediction of maximum oxygen uptake than do prediction equations in the published literature.

3. The prediction of maximum oxygen uptake by multiple regression equations is as reproducable as direct measures of maximum oxygen uptake.

4. Prediction equations based on submaximum data can provide valid estimates of maximum oxygen uptake. ($0.84 < r < 0.90$)

Recommendations for further study

A number of problems in the present study suggest a need for further research.

1. The possibility of including a partial regression coefficient associated with treadmill speed would make the multiple regression equations more versatile.

2. A more precise measure of physical activity is needed. Although techniques are available for assessing activity they are not suitable for clinical use because of the very complicated methods of activity appraisal.

APPENDIX A

DATA FOR THE PREDICTION, REPRODUCIBILITY, AND TEST GROUPS

COLUMN CODE FOR PREDICTION GROUP DATA

VARIABLE	COLUMNS	DATA
1	03-05	AGE IN YEARS
2	06-14	WEIGHT IN KGMS
3	15-23	FAT FREE WEIGHT IN KGMS
4	24-32	RESPIRATORY FREQ.(B/MIN)(8-9 MIN)
5	33-41	MINUTE VENTILATION(LITERS/MIN)(8-9 MIN)
6	42-50	OXYGEN UPTAKE(LITERS/MIN) (8-9 MIN)
7	51-59	RESP. EXCH. RATIO(8-9 MIN)
8	60-68	HEART RATE (B/ MIN)(8-9 MIN)
CARD TWO		
9	02-10	RESPIRATORY FREQ.(B/MIN)(1-2 MIN)
10	11-19	MINUTE VENTILATION LITERS/MIN (1-2 MIN)
11	20-28	OXYGEN UPTAKE (LITERS/MIN)(1-2 MIN)
12	29-37	RESP. EXCH. RATIO (1-2 MIN)
13	38-46	HEART RATE (B/MIN)(1-2 MIN)
14	47-55	HEART RATE DIFFERENCE (2- 9 MIN)
CARD THREE		
15	02-10	RATE OF CHANGE OF RESP. FREQ./MIN
16	11-19	RATE OF CHANGE OF MINUTE VENTILATION/MIN
17	20-28	RATE OF CHANGE OF OXYGEN UPTAKE/MIN
18	29-37	RATE OF CHANGE OF RESP. EXCH. RATIO/MIN
19	38-46	RATE OF CHANGE OF HEART RATE/MIN
20	02-10	PER CENT O2 (8-9 MIN)
21	11-19	TIDAL VOLUME(LITERS/MIN)(8-9 MIN)
22	20-28	PER CENT CO2 (8-9 MIN)
23	29-37	PER CENT O2 (1-2 MIN)
24	38-46	TIDAL VOLUME (LITERS/MIN)(1-2 MIN)
25	47-55	PER CENT CO2 (1-2 MIN)
26	56-64	MAXIMUM OXYGEN UPTAKE(LITERS/MIN)
	65-69	IDENTIFICATION NUMBER

RAW DATA FOR THE INACTIVE GROUP

```
22.   84.540   68.321   35.000   69.711    2.373    1.075  165.000
  24.000   33.846    1.505     .868  126.000   38.999
   1.571    5.123     .123     .029    5.571
   3.404    1.991    3.689    4.448    1.410    3.894    2.911  223
29.   81.360   63.760   41.000   66.200    2.150    1.074  164.000
  34.000   37.619    1.245     .921  120.000   43.999
   1.000    4.082     .129     .021    6.285
   3.248    1.614    3.518    3.310    1.106    3.081    2.597  234
25.   81.820   67.625   33.000   78.616    2.247    1.231  181.000
  21.000   34.737    1.282     .993  138.000   42.999
   1.714    6.268     .137     .033    6.142
   2.858    2.382    3.548    3.693    1.654    3.700    2.543  242
49.   87.270   69.860   28.000   55.305    2.025    1.092  157.000
  21.000   30.852    1.395     .843  115.000   42.000
   1.000    3.493     .090     .035    6.000
   3.662    1.975    4.031    4.521    1.469    3.842    2.600 1011
50.   90.800   72.825   40.000   73.463    2.122    1.081  152.000
  33.000   40.405    1.467     .795  115.000   36.999
   1.000    4.722     .093     .040    5.285
   2.888    1.836    3.152    3.632    1.224    2.921    2.485  864
41.   87.950   68.520   27.000   58.837    2.228    1.074  142.000
  27.000   37.692    1.690     .835  115.000   26.999
   0.000    3.020     .076     .034    3.857
   3.787    2.179    4.099    4.484    1.396    3.778    2.489  855
50.   88.640   75.839   36.000   62.797    2.247    1.058  161.000
  35.000   47.098    1.825     .862  128.000   32.999
    .142    2.242     .060     .028    4.714
   3.579    1.744    3.819    3.876    1.345    3.372    2.376  821
62.   65.450   51.291   27.000   65.893    1.821    1.098  184.000
  32.000   37.522    1.159     .937  153.000   30.999
   -.714    4.052     .094     .022    4.428
   2.763    2.440    3.065    3.089    1.172    2.926    1.821  544
44.   83.410   69.833   32.000   64.353    2.078    1.115  142.000
  28.000   34.015    1.330     .869  115.000   26.999
    .571    4.334     .106     .035    3.857
   3.230    2.011    3.631    3.910    1.214    3.431    2.717  552
53.   87.730   68.752   27.000   56.459    1.930    1.191  165.000
  20.000   32.857    1.324    1.009  138.000   26.999
   1.000    3.371     .086     .026    3.857
   3.418    2.091    4.105    4.030    1.642    4.097    2.222  412
35.   91.360   76.629   23.000   40.112    2.036     .994  140.000
  18.000   20.522    1.138     .771  104.000   35.999
    .714    2.798     .128     .031    5.142
   5.077    1.744    5.077    5.545    1.140    4.305    3.058  424
48.   83.960   69.394   23.000   38.961    1.916     .918  142.000
  19.000   25.046    1.159     .778  113.000   28.999
    .571    1.987     .108     .019    4.142
   4.918    1.693    4.546    4.628    1.318    3.631    2.867  455
```

52. 71.700 61.345 27.000 50.506 1.755 1.073 158.000
15.000 22.498 .876 .890 116.000 42.000
1.714 4.001 .125 .026 6.000
3.475 1.870 3.760 3.893 1.499 3.496 2.066 642
42. 70.590 58.776 26.000 44.990 1.581 1.047 150.000
22.000 26.901 1.002 .811 112.000 37.999
.571 2.584 .082 .033 5.428
3.515 1.730 3.713 3.726 1.222 3.052 2.031 666
53. 85.000 72.204 29.000 56.718 2.046 1.057 149.000
24.000 36.212 1.517 .852 117.000 31.999
.714 2.929 .075 .029 4.571
3.608 1.955 3.847 4.191 1.508 3.604 2.574 1045
52. 79.000 64.207 29.621 55.319 1.943 1.137 165.378
18.000 25.246 1.097 .805 105.000 60.378
1.660 4.296 .120 .047 8.625
3.608 1.955 3.847 4.348 1.402 3.534 2.236 531
38. 73.860 64.775 28.000 44.793 1.850 1.037 142.000
26.000 27.424 1.052 .896 120.000 21.999
.285 2.481 .113 .020 3.142
4.130 1.599 4.314 3.839 1.054 3.473 2.789 614
45. 73.860 62.402 28.000 55.682 2.126 1.031 162.000
22.000 36.815 1.575 .883 110.000 51.999
.857 2.695 .078 .021 7.428
3.818 1.988 3.967 4.279 1.673 3.811 2.562 566
40. 82.730 63.568 31.000 52.177 1.888 1.043 141.000
26.000 30.013 1.134 .853 103.000 37.999
.714 3.166 .107 .027 5.428
3.619 1.683 3.807 3.781 1.154 3.259 2.409 833
62. 87.490 74.721 24.000 80.714 2.405 1.115 139.000
27.000 44.277 1.620 .838 114.000 24.999
-.428 5.205 .112 .039 3.571
2.980 3.363 3.353 3.660 1.639 3.099 2.673 846
45. 81.360 67.868 42.000 77.486 2.123 1.182 176.000
30.000 45.661 1.397 .964 138.000 37.999
1.714 4.546 .103 .031 5.428
2.740 1.844 3.270 3.060 1.522 2.982 2.399 812
39. 86.480 76.240 28.000 54.206 2.255 .985 158.000
22.000 37.064 1.466 .883 136.000 21.999
.857 2.448 .112 .014 3.142
4.161 1.935 4.129 3.955 1.684 3.525 2.957 461
39. 69.550 59.931 26.999 41.837 1.541 1.077 166.999
20.000 25.102 .965 .918 136.000 30.999
.999 2.390 .082 .022 4.428
2.280 1.801 3.549 3.845 1.255 3.561 2.561 651
47. 55.340 50.227 33.000 54.225 1.742 .971 164.000
28.000 40.201 1.212 .869 135.000 28.999
.714 2.003 .075 .014 4.142
3.213 1.643 3.151 3.015 1.435 2.653 1.820 635

RAW DATA FOR INTERLOCKING GROUP

```
28.    85.570    74.783    24.000    40.266     1.753      .982   124.000
  16.000    21.168     1.001      .802   120.000     3.999
   1.142     2.728      .107      .025      .571
   4.355     1.677     4.307     4.729     1.323     3.823     3.172 9432
41.    78.520    68.742    24.000    41.741     1.858      .944   141.000
  16.000    24.934     1.231      .827   107.000    33.999
   1.142     2.401      .089      .016     4.857
   4.451     1.739     4.234     4.939     1.558     4.117     3.583  513
30.    81.820    69.128    25.000    50.106     2.092     1.027   139.000
  23.000    31.430     1.315      .892   111.000    28.000
    .285     2.668      .110      .019     4.000
   4.175     2.004     4.322     4.185     1.366     3.766     3.227  255
35.   102.160    85.531    32.000    67.859     2.446     1.135   153.000
  27.000    35.286     1.651      .748   124.000    28.999
    .714     4.653      .113      .055     4.142
   3.605     2.120     4.122     4.679     1.306     3.532     3.335 1034
41.    74.660    64.106    30.000    59.037     2.093     1.035   156.000
  21.000    29.751     1.265      .829   114.000    42.000
   1.285     4.183      .118      .029     6.000
   3.546     1.967     3.703     4.253     1.416     3.557     2.533  623
50.    85.110    73.600    21.000    49.295     2.246      .959   142.000
  18.000    27.642     1.536      .708   100.000    42.000
    .428     3.093      .101      .035     6.000
   4.556     2.347     4.400     5.557     1.535     3.969     2.533 1063
29.    90.340    75.773    28.000    53.140     2.105     1.024   130.000
  23.000    32.067     1.396      .792    97.000    32.999
    .714     3.010      .101      .033     4.714
   3.962     1.897     4.089     4.354     1.394     3.483     3.352  216
35.    89.770    71.587    23.000    41.650     2.047      .906   123.000
  21.000    28.229     1.346      .795    91.000    31.999
    .285     1.917      .100      .015     4.571
   4.915     1.810     4.484     4.769     1.344     3.823     3.391 1052
47.    81.140    68.677    32.000    48.592     2.036      .974   136.000
  30.000    33.320     1.342      .794   103.000    32.999
    .285     2.181      .099      .025     4.714
   4.190     1.518     4.114     4.027     1.110     3.230     2.871  525
42.    86.820    65.913    18.000    46.951     1.833      .945   122.000
  12.000    24.870     1.108      .752    96.000    25.999
    .857     3.154      .103      .027     3.714
   3.904     2.608     3.723     4.457     2.072     3.384     3.274  433
32.    97.500    81.928    32.000    56.142     2.318      .979   144.000
  30.000    36.815     1.535      .833   116.000    28.000
    .285     2.761      .111      .020     4.000
   4.130     1.754     4.075     4.170     1.227     3.508     3.474  446
29.    82.730    71.795    27.000    50.944     2.065      .998   155.000
  23.000    37.870     1.671      .885   129.000    25.999
    .571     1.867      .056      .016     3.714
   4.055     1.886     4.079     4.412     1.646     3.938     3.474  261
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RAW DATA FOR ACTIVE GROUP

```
31.   69.550   60.783   34.000   43.731    1.706     .975  152.000
  30.000   25.246    1.051     .705  102.000   49.999
    .571    2.640     .093     .038    7.142
   3.902    1.286    3.838    4.165     .841    2.970    2.672  936
29.   75.450   66.170   34.000   47.204    1.897     .917  138.000
  27.000   28.692    1.003     .876  104.000   33.999
   1.000    2.644     .127     .005    4.857
   4.019    1.388    3.719    3.498    1.062    3.094    3.417  126
31.   86.000   73.580   29.000   58.311    2.453    1.004  142.000
  26.000   38.568    1.384     .948  108.000   33.999
    .428    2.820     .152     .007    4.857
   4.207    2.010    4.256    3.589    1.483    3.433    3.808  152
25.   80.000   68.324   35.000   50.901    1.917    1.056  150.000
  29.000   34.994    1.362     .907  116.000   33.999
    .857    2.272     .079     .021    4.857
   3.767    1.454    4.010    3.893    1.206    3.563    3.602  161
41.   74.660   65.477   33.000   48.795    1.678    1.047  120.000
  27.000   27.818     .893     .985   90.000   29.999
    .857    2.996     .112     .008    4.285
   3.439    1.478    3.634    3.210    1.030    3.194    3.103  335
39.   74.620   66.926   28.000   51.883    1.970    1.018  118.000
  24.000   31.222    1.126     .835   90.000   28.000
    .571    2.951     .120     .026    4.000
   3.797    1.852    3.899    3.607    1.300    3.045    3.104  322
44.   79.150   70.020   29.000   46.621    1.612    1.049  117.000
  25.000   27.424     .816    1.022   83.000   33.999
    .571    2.742     .113     .003    4.857
   3.459    1.607    3.660    2.976    1.096    3.074    3.256  344
22.   70.900   63.373   24.000   40.762    1.889     .908  127.000
  26.000   27.627    1.128     .773  104.000   22.999
   -.285    1.876     .108     .019    3.285
   4.635    1.698    4.242    4.085    1.062    3.188    3.375  736
19.   77.840   67.790   32.000   49.932    1.940    1.039  137.000
  24.000   30.049    1.345     .811  105.000   31.999
   1.142    2.840     .085     .032    4.571
   3.886    1.560    4.068    4.476    1.252    3.663    3.493  745
18.   76.820   66.431   24.000   38.235    2.040     .955  139.000
  27.000   29.068    1.326     .821  114.000   24.999
   -.428    1.309     .101     .019    3.571
   5.336    1.593    5.131    4.563    1.076    3.780    3.844  764
40.   61.590   49.586   36.000   45.447    1.512    1.135  147.000
  34.000   35.903    1.079    1.029  112.000   35.000
    .285    1.363     .061     .015    5.000
   3.327    1.262    3.809    3.006    1.055    3.125    2.001  911
45.   64.320   57.590   19.000   42.528    1.598    1.033  158.000
  19.000   40.679    1.431    1.063  145.000   14.000
   0.000     .284     .025    -.004    2.000
   3.759    2.238    3.916    3.517    2.141    3.771    2.407  923
```

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43.   79.320   68.108   31.000   43.978    1.351    1.049  114.000
  25.000   26.112     .696     .923   91.000   22.999
    .857    2.552     .093     .017    3.285
   3.073    1.418    3.255    2.666    1.044    2.493    2.658  316
33.   75.910   63.205   31.000   46.409    1.911    1.000  142.000
  22.000   25.934    1.146     .805   98.000   43.999
   1.285    2.924     .109     .027    6.285
   4.119    1.497    4.151    4.420    1.178    3.588    2.940  944
29.   68.640   56.837   27.000   39.620    1.659    1.010  155.000
  22.000   23.956     .978     .891  108.000   46.999
    .714    2.237     .097     .017    6.714
   4.188    1.467    4.263    4.085    1.088    3.672    2.699  955
54.   70.450   60.707   17.000   32.710    1.867     .917  135.000
  17.000   22.113    1.290     .738  107.000   28.000
   0.000    1.513     .082     .025    4.000
   5.707    1.924    5.266    5.836    1.300    4.340    2.780  942
52.   70.450   61.138   26.000   41.572    1.524    1.005  126.000
  21.000   25.757     .881     .883  102.000   23.999
    .714    2.259     .091     .017    3.428
   3.665    1.598    3.716    3.422    1.226    3.053    3.022  353
44.   74.550   65.951   32.000   46.674    1.826    1.016  118.000
  24.000   28.370    1.024     .891   96.000   21.999
   1.142    2.614     .114     .017    3.142
   3.914    1.458    4.009    3.612    1.182    3.251    3.341  361
21.   67.270   60.231   27.000   50.959    2.109    1.038  146.000
  20.000   30.939    1.364     .865  110.000   35.999
   1.000    2.859     .106     .024    5.142
   4.140    1.887    4.328    4.411    1.546    3.847    3.558  751
21.   77.950   69.674   26.000   43.380    2.144    1.030  133.000
  22.000   26.208    1.221     .852  105.000   28.000
    .571    2.453     .131     .025    4.000
   4.943    1.668    5.124    4.659    1.191    4.002    4.094  713
29.   80.800   71.851   12.000   37.635    1.946     .981  120.000
  12.000   25.845    1.103     .933   93.000   26.999
   0.000    1.684     .120     .006    3.857
   5.171    3.136    5.103    4.268    2.153    4.012    4.530  135
28.   79.320   62.404   28.000   49.307    1.756    1.003  129.000
  17.000   25.566     .854     .877   98.000   30.999
   1.571    3.391     .128     .017    4.428
   3.562    1.760    3.603    3.340    1.503    2.960    3.700  144
22.   69.090   61.226   31.000   48.537    1.951     .962  132.000
  29.000   34.669    1.506     .791  108.000   23.999
    .285    1.981     .063     .024    3.428
   4.019    1.565    3.899    4.344    1.195    3.466    3.566  722
20.   83.640   75.272   22.000   41.640    1.945     .971  139.000
  23.000   35.692    1.531     .908  105.000   33.999
  -.142     .849     .059     .008    4.857
   4.672    1.892    4.568    4.290    1.551    3.928    4.142 9361
```

COLUMN CODE FOR THE REPRODUCIBILITY AND TEST GROUPS

VARIABLE	COLUMNS	DATA
1	02-04	PER CENT CO2 (1-2 MINUTES)
2	05-07	PER CENT 02 (1-2 MINUTES)
3	08-11	MINUTE VENTILATION (LITERS/MIN) (1-2)
4	12-15	OXYGEN UPTAKE(LITERS/MIN)(1-2 MIN)
5	16-19	TIDAL VOLUME(LITERS/MIN)(1-2 MIN)
6	20-23	RESPIRATORY EXCH. RATIO (1-2 MIN)
7	24-25	RESPIRATORY FREQ. (B/MIN)(1-2 MIN)
8	26-28	HEART RATE (B/MIN)(1-2 MIN)
9	29-31	PER CENT CO2 (8-9 MIN)
10	32-34	PER CENT 02 (8-9 MIN)
11	35-38	MINUTE VENTILATION(LITERS/MIN(8-9 MIN)
12	39-42	OXYGEN UPTAKE(LITERS/MIN)(8-9 MIN)
13	43-46	TIDAL VOLUME(8-9 MIN)
14	47-50	RESP. EXCH. RATIO (8-9 MIN)
15	51-52	RESPIRATORY FREQ.(8-9 MIN)
16	53-55	HEART RATE (8-9 MIN)
17	56-57	AGE IN YEARS
18	58-66	BODY WEIGHT IN KGMS
19	67-71	FAT FREE WEIGHT IN KGMS
CARD TWO **		
20	03-07	RATE OF CHANGE OF RESP. FREQ/MIN
21	03-07	RATE OF CHANGE OF MINUTE VENTILATION
22	14-19	RATE OF CHANGE OF OXYGEN UPTAKE/MIN
23	20-25	RATE OF CHANGE OF RESP. EXCH. RATIO
24	26-31	RATE OF CHANGE OF HEART RATE/MIN
25	32-37	HEART RATE DIFFERENCE FROM 2-9 MINUTES
26	38-43	PER CENT CO2 (1-2 MIN)
27	44-49	PER CENT 02 (8-9 MIN)
	50-53	IDENTIFICATION NUMBER

** VARIABLES 20 THROUGH 24 ARE MULTIPLIED BY 10 TO THE -3

RAW DATA FOR THE REPRODUCIBILITY STUDY

```
3545651703 9621419 62712 83455544340618522270 83615106354843 7273 6141
   428  2432   127    29  3285    23   354   4551921
3444891563 7641563 70310 85453571340219422268 79315109354843 7273 6141
   714  2627   168    12  3428    24   344   4538121
4115102106107410O2 80621 964775353954211516 47 89224116368929 7546 6209
   428  2640   148    12  2857    20   411   4771922
4164412693118714 96 94318105469481426820521940 97522128368929 7546 6209
   571  2250   123     4  3285    23   416   4698122
3163992457 9801293 79219 964465263744196917 82 84821133301530 6863 6263
   285  1838   141     7  5285    37   316   4462909
3423762965111415 60 91019106450501373518711778 89821132301530 6863 6263
   285  1100   108    -1  3714    26   342   4508109
3033842708103910 83 78925 85392434430418671594 90327119425323 7173 6133
   285  2280   118    16  4857    34   303   3928118
3033842708103910 83 78925 85392434430418671594 90327119425323 7173 6133
   285  2280   118    16  4857    34   303   3928118
4124773497166812 05 86429 79468500552227611781 93631 96420030 9182 7794
   285  2892   156    10  2428    17   412   4682910
3704014026161419 17 92321 92474471568726782106100627118420030 9182 7794
   857  2372   152    11  3714    26   370   4748110
4134633037140615 18 89220106461491410720161785 93923125311031 6682 5856
   428  1528    87     6  2714    19   413   4612912
3894422555112912 77 88020106454445399517771664102024126311031 6682 5856
   571  2057    92    20  2857    20   389   4548112
3123803805144521 13 82118103377330520617172082114225139309626 7168 6040
  1000  2001    38    45  5142    36   312   3772914
3653863323128218 46 94618107366324566318341887113030150309626 7168 6040
  1714  3342    78    26  6142    43   365   3668114
3504132853117814 26 84720 84537428432518511491125529135316527 7136 6014
  1285  2102    96    58  7285    51   350   5372916
3594252962125814 10 84521 87546436450219621452125231140316527 7136 6014
  1428  2200   100    58  7571    53   359   5462116
3734852397116223 97 76910 91417441465720532587 94618130370125 8432 6767
  1142  3228   127    25  5571    39   373   4172913
3834742955140029 55 80810 88420432535223122548 97221130370125 8432 6767
  1571  3424   130    23  6000    42   383   4208113
3063294763156714 00 93034118376384543020851357 97940136305832 7488 5990
   857   952    74     7  2571    18   306   3763901
2993134155130012 22 95534112346333611820371529103940143305832 7488 5990
   857  2804   105    11  4428    31   299   3468101
3804094855198515 66 92931136389464635129461814 83835160296532 7273 5996
   571  2137   137   -12  3428    24   380   3893902
3364083744152712 48 82430130405407547522281710 99532160296532 7273 5996
   285  2472   100    24  4285    30   336   4058102
4034832328112416 62 83414 99460477406419382257 96418128293429 8364 6428
   571  2480   116    18  4142    29   403   4603903
4164742615123920 11 87813110439444452920102383 98919136293429 8364 6428
   857  2734   110    15  3714    26   416   4398103
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RAW DATA FOR THE ACTIVES

```
3263613727134513 80 9032710937339456152212140 3 94740127392636 8080 7070
  1857  2697   123     6  2571    18   326   3731120
3444891563 7641563 70310 8545357134021942226 8 79315109354843 7273 6141
   714  2627   168    12  3428    24   344   4531121
4164412693.1871496 9431810546948142682052194 0 97522128368929 7546 6209
   571  2250   123     4  3285    23   416   4691122
3694483067137411 79 8242611737945338741754121 0 83732134344821 6341 5567
   857  1152    54     1  2428    17   369   3791123
3094033278132114 25 7672310335037853342016136 7 92639130373722 8014 6938
  2285  2937    99    22  3857    27   309   3501124
4165632009113120 09 7391010346255541092280186 7 83222140373329 7591 6747
  1714  3000   164    13  5285    37   416   4621125
3584123200131815 23 8692111644950940222047191 5 8822113835662 1 7568 6730
     0  1174   104     1  3142    22   358   4491129
3704014026161419 17 92321 9247447156872678210610062711842003 0 9182 7794
   857  2372   152    11  3714    26   370   4742110
4304243652154813521014271064524445570247318561018301333791 31 9068 7073
   428  2740   132     0  3857    27   430   4522111
3894422555112912 77 8802010645444539951777166410202412631103 1 6682 5856
   571  2057    92    20  2857    20   389   4542112
3834742955140029 55 80810 8842043253522312254 8 97221130396525 8432 6767
  1571  3424   130    23  6000    42   383   4202113
4733922660104295012072 8 9547745642191923136010463113038731 8 7386 6285
   428  2227   125   -22  5000    35   473   4771142
3594252962125814 10 84521 8754643645021962145212523114031652 7 7136 6014
  1428  2200   100    58  7571    53   359   5462116
4085163129161415 64 7912010345148250552436180 5 93628129355626 7773 6501
  1142  2751   117    20  3714    26   408   4512115
3653863323128218 46 9461810736632456631834188711303015030962 6 7168 6040
  1714  3342    78    26  6142    43   365   3662114
```

RAW DATA FOR THE INACTIVES

```
2993134155130012222 955341123463336118203715291039401433058327488 5990
   857  2804   105    11  4428    31   299   3463101
3364083744152712488 824301304054075475222817109953216029653272736 5996
   285  2472   100    24  4285    30   336   4053102
4164742615123920118 781311043944445292010238398919136293429 8364 6428
   857  2734   110    15  3714    26   416   4393103
4244653972184615889 122512539034862782184196111213215027764780916757
  1000  3294    48    29  3571    25   424   3903104
4214493362150922419 381512035429675642238244011963116924163984326655
  2285  6002   104    36  7000    49   421   3543105
3504292739117510538 162611339543647482070153190631142304934 7455 6340
   714  2870   127    12  4142    29   350   3953106
3744543160143418588 241711840338648201860209510442316025352262485332
   857  2371    60    31  6000    42   374   4033107
3794844105198614668 783281204244406549288121839643016332612810375 7058
   285  3491   127    25  6142    43   379   4243108
4403402457 3351170129421 974864223913165119561152201333149207591 6739
  -142  2080   116   -20  5142    36   440   4863145
4403842844109211851146241094584683944184514089792814130191976186436
   571  1571   107   -23  4571    32   440   4583143
4513921548 606 737115121120423434400417371601 97525158317228 8568 7488
   571  3508   161   -25  5428    38   451   4233141
3203593951141823248911712838740452992140240895822164307223 7326 6223
   714  1925   103     9  5142    36   320   3873150
3763543537125217681062201203983995078202624189972115830882371006031
   142  2201   110    -9  5428    38   376   3983151
```

APPENDIX B

```
PROGRAMME FOR STEPWISE MULTIPLE REGRESSION **

      TYPE 790
  790 FORMAT(20HSW2 TYPES RSQRS ONLY)
      TYPE 791
  791 FORMAT(30HSW3 ALLOWS MATRIX MANIPULATION)
      TYPE 796
  796 FORMAT(42HSW4 RESETS FIRST IND. FOR STEPWISE SEARCH.)
      TYPE 332
  332 FORMAT(51HSW4 MUST NOT BE TURNED ON UNTIL SW3 HAS SET VECTOR.)
      TYPE 792
  792 FORMAT(80HTYPE NUMBER OF IND.,DEP.,AND TOTAL NUMBER OF RELOCATABLE
     1 TERMS ALSO IDS OF BOTH.)
      TYPE 794
  794 FORMAT(43HTO EXIT FROM RELOCATABLE MATRIX SET NX= 40.)
      TYPE 795
  795 FORMAT(71HIF YOU WISH A REGRESSION PUNCHED TURN SW2 OFF AND REDO F
     1ELOCATABLE SET.  )
      TYPE 793
  793 FORMAT(33HSET SWITCHES DESIRED,PRESS START.)
      PAUSE
      DIMENSION A(39,39),X(39),SUM(39),REG(39),BZERO(39),RES(39),RSQ(39)
      DIMENSION CON(39),ID(39),UM(39)
      DEFINE DISK(10,200)
    1 READ 100,NPROG,JOB,NX,NY,IX
  100 FORMAT(I3,I5,I3,I3,I2)
      IF(NPROG-56) 2,3,2
    2 PRINT 101,NPROG
  101 FORMAT(24HTHIS IS PROGRAM 56, NOT I3)
      PAUSE
      GO TO 1
    3 CONTINUE
      NVAR=NX+NY
C   READ AND PUNCH SELECTION VECTOR
      DO 4 I=1,NVAR
      READ 102,ID(I)
    4 CONTINUE
  102 FORMAT(I5)
      READ 109,NV
  109 FORMAT(8X,I3)
      DO 5 I=1,NV
    5 READ 110,MMM
  110 FORMAT(I1)
      READ 111,NOBS
  111 FORMAT(1X,I5)
C   SELECT AND STORE SUMS
      DO 60 I=1,NV
      READ 501,ELEM
  501 FORMAT(27X,E15.8)
      DO 61 K=1,NVAR
      IF(I-ID(K)) 61,62,61
   61 CONTINUE
```

```
      GO TO 60
   62 SUM(K)=ELEM
      UM(K)=ELEM
   60 CONTINUE
C  SELECT AND STORE SUMS OF SQUARES AND PRODUCTS
      DO 50 I=1,NV
      DO 50 J=I,NV
      READ 500,ELEM
  500 FORMAT(15X,E15.8)
      DO 51 K=1,NVAR
      IF(I-ID(K)) 51,52,51
   51 CONTINUE
      GO TO 50
   52 DO 53 L=1,NVAR
      IF(J-ID(L)) 53,54,53
   53 CONTINUE
      GO TO 50
   54 IF(K-L) 55,56,55
   56 A(K,L)=ELEM
      X(K)=SQRTF(A(K,L))
      GO TO 50
   55 A(L,K)=ELEM
      A(K,L)=ELEM
   50 CONTINUE
      NK=NVAR
      N=NX
      NN=N+1
      I=1
      RECORD(I) A, UM,X
       I=1
      FIND(I)
C REARRANGE THE ARRAY
  998 IF(SENSE SWITCH 3)910,911
  910 CONTINUE
  999 TYPE 797
  797 FORMAT(25HRESET RELOCATABLE MATRIX.)
  476 CONTINUE
      I=1
      FETCH(I) A, UM,X
      I=1
      FIND(I)
      IF(SENSE SWITCH 4)472,473
  472 ID(1)=ID(1)+1
  479 DO 480 I=2,NX
      IF(ID(1)-ID(I))480,14,480
  480 CONTINUE
      NT=NX+1
  470 TYPE 471,ID(1)
      PUNCH 471,ID(1)
  471 FORMAT(8HID(1) = I2)
```

```
      IF(ID(1)-ID(NT))921,474,474
  474 TYPE 475
  475 FORMAT(36HSELECT VARIABLE DESIRED SW2 SW4 OFF.)
      TYPE 471
      ACCEPT 478,ID(1)
  478 FORMAT(I2)
      GO TO 859
  473 CONTINUE
  929  ACCEPT 908,NX,NY,NVAR,(ID(I),I=1,NVAR)
      IF(NVAR-40)859,859,999
  859 IF(NX-40)921,922,922
  922 TYPE 923
  923 FORMAT(19HALL DATA PROCESSED.)
      GO TO 925
  921 CONTINUE
  908 FORMAT(212,3912)
      IC=0
      DO 600 I=1,NV
      IC=IC+1
      IB=ID(IC)
      SUM(I)= UM(IB)
      DO 600 J=I,NV
      ELEM=A(I,J)
      DO 510 K=1,NVAR
      IF(I-ID(K))510,520,510
  510 CONTINUE
      GO TO 600
  520 DO 530 L=1,NVAR
      IF(J-ID(L))530,540,530
  530 CONTINUE
      GO TO 600
  540 IF(K-L)550,560,550
  560 A(K,L)=ELEM
      X(K)=SQRTF(ELEM)
      GO TO 600
  550 A(L,K)=ELEM
      A(K,L)=ELEM
  600 CONTINUE
  909 CONTINUE
      NVAR=NX+NY
      NK=NVAR
      N=NX
      NN=N+1
  911 CONTINUE
C  FIND REQUIRED INVERSE
  205 DO 217 L=1,N
      RECIP=1.0/A(L,L)
      DO 216 I=1,N
      IF(I-L) 206,207,208
  206 R=A(I,L)*RECIP
```

```
      GO TO 209
  207 R=0.0
      GO TO 209
  208 R=A(L,I)*RECIP
  209 DO 212 J=I,NK
      IF(J-L) 210,212,211
  210 A(I,J)=A(I,J)-(R*A(J,L))
      GO TO 212
  211 A(I,J)=A(I,J)-(R*A(L,J))
  212 CONTINUE
      IF(I-L) 213,214,215
  213 A(I,L)=R
      GO TO 216
  214 A(L,L)=-RECIP
      GO TO 216
  215 A(L,I)=R
  216 CONTINUE
      DO 217 NM=NN,NK
  217 A(L,NM)=A(L,NM)*RECIP
C   COMPUTE INTERCEPTS AND SUMS OF SQUARES DUE TO THE MODEL
      DO 10 J=NN,NK
      REG(J)=0.0
      BZERO(J)=SUM(J)
      DO 11 I=1,N
      REG(J)=REG(J)+A(J,I)*A(I,J)
   11 BZERO(J)=BZERO(J)-A(I,J)*SUM(I)
      RES(J)=A(J,J)-REG(J)
   10 RSQ(J)=REG(J)/A(J,J)
      IF(IX-1) 71,70,71
   70 DO 72 I=1,NX
      DO 72 J=I,NX
      ELEM=-A(I,J)
   72 PUNCH 150,JOB,I,J,ELEM
  150 FORMAT(I5,I3,I3,E15.8)
   71 NTOT=NOBS-1
      ATOT=NTOT
      AY=NY
      NERR=NTOT-NX
      AERR=NERR
      NB=1
C   PUNCH REGRESSION ANALYSIS FOR EACH DEPENDENT VARIABLE
      DO 14 J=NN,NK
      IF(SENSE SWITCH 2)900,901
  900 TYPE 907,RSQ(J),(ID(I),I=1,NVAR)
      PUNCH 907,RSQ(J),(ID(I),I=1,NVAR)
  907 FORMAT(2HR2,3H = F10.6,2313/1613)
      GO TO 14
  901 CONTINUE
  997 PUNCH 103,JOB,J
  103 FORMAT(/28H  REGRESSION ANALYSIS OF JOBI5,10H, VARIABLEI3/)
```

```
      PUNCH 104
  104 FORMAT(6HSOURCE3X2HDF1X7HMEAN SQ15X5HCOEF 10X7HST COEF4X4HMEAN)
      TOTMS=A(J,J)/ATOT
      N=0
      TYPE 340,N,BZERO(J),SUM(J)
      PUNCH 105,NTOT,TOTMS,N,BZERO(J),SUM(J)
  105 FORMAT(7H TOTAL I4,E14.8,2X2HB(I3,2H)=E14.8,10H                ,E14.8)
      DO 15 I=1,NX
      BMS=A(I,J)*A(I,J)/(-A(I,I))
      STAN=A(I,J)*X(I)/X(J)
      TYPE  340,ID(I),A(I,J),SUM(I)
  340 FORMAT(12X,2HB(I3,2H)=F10.5,2X,F10.5)
   15 PUNCH 106,ID(I),NB,BMS,ID(I),A(I,J),STAN,SUM(I)
  106 FORMAT(3H B(I3,1H)I4,E14.8,2X2HB(I3,2H)=E14.8,E10.4,E14.8)
  341 FORMAT(12X,2HB(I3,2H)=F9.5,2X,F9.5)
      AMOD=NX
      BMOD=REG(J)/AMOD
      TYPE 342,RSQ(J)
      PUNCH 342,RSQ(J)
  342 FORMAT(12X,4HRSQ=F9.6)
      PUNCH 107,NX,BMOD,RSQ(J)
  107 FORMAT(7H MODEL I4,E14.8,7X7HR SQR =E15.8)
      RES(J)=RES(J)/AERR
      PUNCH 108,NERR,RES(J)
   14 CONTINUE
  108 FORMAT(7H ERROR I4,E14.8)
      IF(SENSE SWITCH 4)476,477
  477 CONTINUE
      IF(SENSE SWITCH 3)998,463
  463 CONTINUE
      GO TO 1
  925 CALL EXIT
      END
**  PROGRAMME A MODIFIED VERSION
OF A PROGRAMME DEVELOPED AT
UTAH STATE UNIVERSITY
BY MR. REX L. HURST

PROGRAMME FOR CALCULATING THE PREDICTED MAXIMUM UPTAKES

      DIMENSION D(5),F(5)
  222 CONTINUE
      TYPE 200
  200 FORMAT(12HEQUATION SET)
      ACCEPT 1,II
```

```
  100 READ 101,P2,V2,V02,TV2,RQ2,F2,HR2,P9,V9,V09,TV9,RQ9,F9,HR9, 0X1,AG
     1E,WTT,WT,DF,DV,DV0,DRQ,DHR,HRD,C02,C09,ID
  101 FORMAT(1X,2(3X,F3.2,F4.2,3F4.3,F2.0,F3.0),F4.3,F2.0,2F5.2,6X    /1X
     1,8F6.0,I4)
      DF=DF/1000.
      DV=DV/1000.
      DV0=DV0/1000.
      DRQ=DRQ/1000.
      DHR=DHR/1000.
      C09=C09/100.
      C02=C02/100.
    1 FORMAT(I1)
C ACTIVES EQUATIONS
      IF(II-2)2,3,4
    2 CONTINUE
      P1=2.966-8.7708*DRQ-.0308*AGE+.0259*WT-.01268*HR9+.2543*C09+.3303*
     1TV2
      P2=4.1744-.03468*AGE+.023105*WT-.01441*HR9+.49783*TV2
      GO TO 333
    3 CONTINUE
      GO TO 333
C THESE ARE THE INACTIVE EQUATIONS
    4 CONTINUE
      IF(II-3)9,9,10
    9 CONTINUE
      P8=P2
      P1=3.6188+.2528*TV9-.02199*AGE+.03253*WT-2.5874*RQ9
      P2=3.2235-.01717*F9-.02159*AGE+.02898*WT-.00725*HR9
      GO TO 333
   10 CONTINUE
C     TOTAL PREDICTION GROUP EQUATIONS
      P1=4.5475+.2436*C09-.0285*AGE-.01656*HR9+.6764*TV2
      P2=5.8836-.03285*AGE-.01765*HR9-.17458*DF+.74794*TV2
  333 CONTINUE
      D(1)=P1-0X1
      D(2)=P2-0X1
      IF(SENSE SWITCH 2)365,366
  366 CONTINUE
      PUNCH 201,0X1,P1,D(1),P2,D(2),ID
      IF(V2-0.)222,222,100
  667 CONTINUE
  365 CONTINUE
    6 CONTINUE
      PUNCH 206,0X1,(D(I),I=1,2),ID
      TYPE  206,0X1,(D(I),I=1,2),ID
  206 FORMAT(3F6.3,I5)
      IF(V2-0.)222,222,100
  201 FORMAT(5F9.3,I5)
      END
```

```
PROGRAMME FOR CALCULATING TIDAL VOL. RQ AND 02 UPTAKE

      DIMENSION VAR(14),IR(16),ID(8)
  103 CONTINUE
      READ 100,(VAR(I),I=1,13),IF,DI
  100 FORMAT(1X,2(2F3.2,F4.2,F2.0,F3.0),F4.3,F2.0,F5.2,I5,A4)
      V02=VAR(2)*VAR(3)
      TV2=VAR(3)/VAR(4)
      V09=VAR(7)*VAR(8)
      TV9=VAR(8)/VAR(9)
      IR(1)=VAR(1)*100.
      IR(2)=VAR(2)*100.
      IR(3)=VAR(3)*100.
      IR(4)=V02*10.
      IR(5)=TV2*1000.
      R=(VAR(1)/VAR(2))+.0005
      IR(6)=R*1000.
      IR(7)=VAR(4)
      IR(8)=VAR(5)
      IR(9)=VAR(6)*100.
      IR(10)=VAR(7)*100.
      IR(11)=VAR(8)*100.
      IR(12)=V09*10.
      R9=(VAR(6)/VAR(7))+.0005
      IR(13)=TV9*1000.
      IR(14)=R9*1000.
      IR(15)=VAR(9)
      IR(16)=VAR(10)
      IA=VAR(11)*1000.
      IB=VAR(12)
      IC=VAR(13)*100.
      ID(1)=((VAR(9)-VAR(4))/7.)*1000.
      ID(2)=((VAR(8)-VAR(3))/7.)*1000.
      ID(3)=((V09-V02)/7.)*10.
      ID(4)=(R9-R)/7. *1000.
      ID(5)=(VAR(10)-VAR(5))/7. *1000.
      ID(6)=VAR(10)-VAR(5)
      ID(7)=VAR(1)*100.
      ID(8) =VAR(6)*100.
  111 CONTINUE
  110 CONTINUE
      PUNCH 101,(IR(I),I=1,16),IA,IB,IC,IF,    (ID(I),I=1,8),DI
  101 FORMAT(1X,2(2I3,4I4,I2,I3),I4,I2,2I5,6X    /1X,8I6,A4)
      GO TO 103
      END
```

APPENDIX C

The following pages show the stepwise procedure for developing the regression equations. One equation build up is shown and it is for the total prediction group

Explanation of form

ID(1) indicates which variable is to be added next
R2 is the code for the coefficient of determination
26 is the dependent variable number
All other numbers are variables which have been added to R2

Variable codes used in this section

1	Age in years
2	Weight in kilograms
3	Fat free weight in kilograms
4	Respiratory Freq. 8-9 min
5	Minute ventilation 8-9 min
6	Oxygen uptake 8-9 min
7	Resp. Exch. Ratio 8-9 min
8	Heart rate 8-9 min
9	Respiratory freq. 1-2 min
10	Minute ventilation 1-2 min
11	Oxygen uptake 1-2 min
12	Resp. exch. ratio 1-2 min
13	Heart rate 1-2 min
14	Heart rate difference
15	Rate of change of resp. freq.
16	Rate of change of minute ventilation
17	Rate of change of oxygen uptake
18	Rate of change of resp. exch. ratio
19	Rate of change of heart rate
20	Per cent 02 8-9 min
21	Tidal volume 8-9 min
22	Per cent CO_2 8-9 min
23	Per cent 02 1-2 min
24	Tidal Volume 1-2 min
25	Per cent CO_2 1-2 min
26	Maximum oxygen uptake

```
R2 =     .466937   1 26
ID(1) =   2
R2 =     .027247   2 26
ID(1) =   3
R2 =     .132699   3 26
ID(1) =   4
R2 =     .191586   4 26
ID(1) =   5
R2 =     .170594   5 26
ID(1) =   6
R2 =     .015117   6 26
ID(1) =   7
R2 =     .195012   7 26
ID(1) =   8
R2 =     .352245   8 26
ID(1) =   9
R2 =     .120985   9 26
ID(1) =  10
R2 =     .043484  10 26
ID(1) =  11
R2 =     .002151  11 26
ID(1) =  12
R2 =     .000246  12 26
ID(1) =  13
R2 =     .252945  13 26
ID(1) =  14
R2 =     .104526  14 26
ID(1) =  15
R2 =     .034240  15 26
ID(1) =  16
R2 =     .191946  16 26
ID(1) =  17
R2 =     .015474  17 26
ID(1) =  18
R2 =     .203209  18 26
ID(1) =  19
R2 =     .104498  19 26
ID(1) =  20
R2 =     .334049  20 26
ID(1) =  21
R2 =     .019495  21 26
ID(1) =  22
R2 =     .335252  22 26
ID(1) =  23
R2 =     .074192  23 26
ID(1) =  24
R2 =     .107338  24 26
ID(1) =  25
R2 =     .140320  25 26
```

```
 ID(1) =  3
 R2 =     .544073  3   1 26
 ID(1) =  4
 R2 =     .645011  4   1 26
 ID(1) =  5
 R2 =     .551444  5   1 26
 ID(1) =  6
 R2 =     .467163  6   1 26
 ID(1) =  7
 R2 =     .574732  7   1 26
 ID(1) =  8
 R2 =     .702649  8   1 26
 ID(1) =  9
 R2 =     .542551  9   1 26
 ID(1) = 10
 R2 =     .487159 10   1 26
 ID(1) = 11
 R2 =     .466958 11   1 26
 ID(1) = 12
 R2 =     .475916 12   1 26
 ID(1) = 13
 R2 =     .608155 13   1 26
 ID(1) = 14
 R2 =     .567793 14   1 26
 ID(1) = 15
 R2 =     .536962 15   1 26
 ID(1) = 16
 R2 =     .563745 16   1 26
 ID(1) = 17
 R2 =     .467263 17   1 26
 ID(1) = 18
 R2 =     .535024 18   1 26
 ID(1) = 19
 R2 =     .567765 19   1 26
 ID(1) = 20
 R2 =     .631227 20   1 26
 ID(1) = 21
 R2 =     .529252 21   1 26
 ID(1) = 22
 R2 =     .608827 22   1 26
 ID(1) = 23
 R2 =     .499381 23   1 26
 ID(1) = 24
 R2 =     .547683 24   1 26
 ID(1) = 25
 R2 =     .50:392 25   1 26
 ID(1) = 26
 R2 =     .710323  2   1  8 26
```

```
 ID(1) =  3
 R2 =     .741838  3  1  8 26
 ID(1) =  4
 R2 =     .758262  4  1  8 26
 ID(1) =  5
 R2 =     .702708  5  1  8 26
 ID(1) =  6
 R2 =     .748704  6  1  8 26
 ID(1) =  7
 R2 =     .706474  7  1  8 26
 ID(1) =  9
 R2 =     .719596  9  1  8 26
 ID(1) = 10
 R2 =     .711236 10  1  8 26
 ID(1) = 11
 R2 =     .740394 11  1  8 26
 ID(1) = 12
 R2 =     .705069 12  1  8 26
 ID(1) = 13
 R2 =     .705534 13  1  8 26
 ID(1) = 14
 R2 =     .705535 14  1  8 26
 ID(1) = 15
 R2 =     .727618 15  1  8 26
 ID(1) = 16
 R2 =     .710908 16  1  8 26
 ID(1) = 17
 R2 =     .702701 17  1  8 26
 ID(1) = 18
 R2 =     .714661 18  1  8 26
 ID(1) = 19
 R2 =     .705530 19  1  8 26
 ID(1) = 20
 R2 =     .747728 20  1  8 26
 ID(1) = 21
 R2 =     .779726 21  1  8 26
 ID(1) = 22
 R2 =     .759197 22  1  8 26
 ID(1) = 23
 R2 =     .723425 23  1  8 26
 ID(1) = 24
 R2 =     .794245 24  1  8 26
 ID(1) = 25
 R2 =     .756571 25  1  8 26
 ID(1) = 26
 R2 =     .796234  2  1  8 24 26
 ID(1) =  3
 R2 =     .811901  3  1  8 24 26
 ID(1) =  4
 R2 =     .800403  4  1  8 24 26
```

```
 ID(1) =  5
 R2 =     .795612  5   1   8 24 26
 ID(1) =  6
 R2 =     .812528  6   1   8 24 26
 ID(1) =  7
 R2 =     .797260  7   1   8 24 26
 ID(1) =  9
 R2 =     .796849  9   1   8 24 26
 ID(1) = 10
 R2 =     .797100 10   1   8 24 26
 ID(1) = 11
 R2 =     .809520 11   1   8 24 26
 ID(1) = 12
 R2 =     .794253 12   1   8 24 26
 ID(1) = 13
 R2 =     .796440 13   1   8 24 26
 ID(1) = 14
 R2 =     .796441 14   1   8 24 26
 ID(1) = 15
 R2 =     .815892 15   1   8 24 26
 ID(1) = 16
 R2 =     .803554 16   1   8 24 26
 ID(1) = 17
 R2 =     .794245 17   1   8 24 26
 ID(1) = 18
 ID(1) = 19
 R2 =     .796438 19   1   8 24 26
 ID(1) = 20
 R2 =     .820584 20   1   8 24 26
 ID(1) = 21
 R2 =     .79L199 21   1   8 24 26
 ID(1) = 22
 R2 =     .829190 22   1   8 24 26
 ID(1) = 23
 R2 =     .804055 23   1   8 24 26
 ID(1) = 25
 R2 =     .815094 25   1   8 24 26
 ID(1) = 26
 R2 =     .840281  3   1   8 22 24 26
 ID(1) =  4
 R2 =     .834509  4   1   8 22 24 26
 ID(1) =  5
 R2 =     .837299  5   1   8 22 24 26
 ID(1) =  6
 R2 =     .837571  6   1   8 22 24 26
 ID(1) =  7
 R2 =     .829514  7   1   8 22 24 26
```

```
 ID(1) = 10
 R2 =     .848208 10   1   8 22 24 26
 ID(1) = 11
 R2 =     .836578 11   1   8 22 24 26
 ID(1) = 12
 R2 =     .833774 12   1   8 22 24 26
 ID(1) = 13
 R2 =     .833781 13   1   8 22 24 26
 ID(1) = 14
 R2 =     .833781 14   1   8 22 24 26
 ID(1) = 15
 R2 =     .836646 15   1   8 22 24 26
 ID(1) = 16
 R2 =     .829300 16   1   8 22 24 26
 ID(1) = 17
 R2 =     .829213 17   1   8 22 24 26
 ID(1) = 18
 R2 =     .831971 18   1   8 22 24 26
 ID(1) = 19
 R2 =     .833780 19   1   8 22 24 26
 ID(1) = 20
 R2 =     .830366 20   1   8 22 24 26
 ID(1) = 21
 R2 =     .831262 21   1   8 22 24 26
 ID(1) = 23
 R2 =     .836313 23   1   8 22 24 26
 ID(1) = 25
 R2 =     .831459 25   1   8 22 24 26
 ID(1) = 26
 R2 =     .817723  2   1   8 15 24 26
 ID(1) =  3
 R2 =     .829383  3   1   8 15 24 26
 ID(1) =  4
 R2 =     .815941  4   1   8 15 24 26
 ID(1) =  5
 R2 =     .816242  5   1   8 15 24 26
 ID(1) =  6
 R2 =     .826465  6   1   8 15 24 26
 ID(1) =  7
 R2 =     .815991  7   1   8 15 24 26
 ID(1) =  9
 R2 =     .815941  9   1   8 15 24 26
 ID(1) = 10
 R2 =     .815893 10   1   8 15 24 26
 ID(1) = 11
 R2 =     .819239 11   1   8 15 24 26
```

```
ID(1) = 12
R2 =     .816112 12   1   8 15 24 26
ID(1) = 13
R2 =     .815952 13   1   8 15 24 26
ID(1) = 14
R2 =     .815952 14   1   8 15 24 26
ID(1) = 16
R2 =     .816777 16   1   8 15 24 26
ID(1) = 17
R2 =     .821589 17   1   8 15 24 26
ID(1) = 18
R2 =     .816601 18   1   8 15 24 26
ID(1) = 19
R2 =     .815952 19   1   8 15 24 26
ID(1) = 20
R2 =     .825166 20   1   8 15 24 26
ID(1) = 21
R2 =     .816271 21   1   8 15 24 26
ID(1) = 22
R2 =     .836646 22   1   8 15 24 26
ID(1) = 23
R2 =     .820609 23   1   8 15 24 26
ID(1) = 25
R2 =     .828163 25   1   8 15 24 26
```

The following pages indicate the coefficients of determination

The standard coefficients

The mean squares

and the means for each step of the total prediction equations

Variable codes used in this section

1 Age in years
2 Weight in kilograms
3 Fat free weight in kilograms
4 Respiratory Freq. 8-9 min
5 Minute ventilation 8-9 min
6 Oxygen uptake 8-9 min
7 Resp. Exch. Ratio 8-9 min
8 Heart rate 8-9 min
9 Respiratory freq. 1-2 min
10 Minute ventilation 1-2 min
11 Oxygen uptake 1-2 min
12 Resp. exch. ratio 1-2 min
13 Heart rate 1-2 min
14 Heart rate difference
15 Rate of change of resp. freq.
16 Rate of change of minute ventilation
17 Rate of change of oxygen uptake
18 Rate of change of resp. exch. ratio
19 Rate of change of heart rate
20 Per cent 02 8-9 min
21 Tidal volume 8-9 min
22 Per cent CO_2 8-9 min
23 Per cent 02 1-2 min
24 Tidal Volume 1-2 min
25 Per cent CO_2 1-2 min
26 Maximum oxygen uptake

REGRESSIOI. ANALYSIS OF JOB 4, VARIABLE 2

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.44245397E+01		.30007000E+01
B(1)	1	.10849542E+02	B(1)=	-.37257036E-01	-.6833E+00	.38216666E+02
		RSQ= .466937				
MODEL	1	.10849543E+02		R SQR = .46693761E+00		
ERROR	58	.21355150E+00				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 2

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.75048030E+00		.30007000E+01
B(3)	1	.30833339E+01	B(3)=	.33554620E-01	.3642E+00	.67061400E+02
		RSQ= .132699				
MODEL	1	.30833340E+01		R SQR = .13269910E+00		
ERROR	58	.34745165E+00				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 3

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.69135474E+01		.30007000E+01
B(8)	1	.54768864E+01	B(8)=	-.18549025E-01	-.4925E+00	.14348961E+03
B(1)	1	.81418210E+01	B(1)=	-.32741087E-01	-.6005E+00	.38216666E+02
		RSQ= .702649				
MODEL	2	.81632145E+01		R SQR = .70264930E+00		

REGRESSION ANALYSIS OF JOB 4, VARIABLE 4

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.58811654E+01		.30007000E+01
B(24)	1	.21282838E+01	B(24)=	.76138871E+00	.3034E+00	.13791333E+01
B(1)	1	.75319255E+01	B(1)=	-.31568131E-01	-.5789E+00	.38216666E+02
B(8)	1	.57289995E+01	B(8)=	-.18984603E-01	-.5040E+00	.14348961E+03
SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.75048030E+00		.30007000E+01
		RSQ= .794245				
MODEL	3	.61515710E+01		R SQR = .79424540E+00		
ERROR	56	.85371732E-01				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 5

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.45474668E+01		.30007000E+01
B(22)	1	.81196414E+00	B(22)=	.24360977E+00	.2113E+00	.40534833E+01
B(1)	1	.56551046E+01	B(1)=	-.28515426E-01	-.5229E+00	.38216666E+02
B(8)	1	.39152515E+01	B(8)=	-.16567513E-01	-.4399E+00	.14348961E+03
B(24)	1	.16263289E+01	B(24)=	.67636356E+00	.2696E+00	.13791333E+01
		RSQ= .829190				
MODEL	4	.48166692E+01		R SQR = .82919033E+00		
ERROR	55	.72160963E-01				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 6

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.35382090E+01		.30007000E+01
B(9)	1	.46530000E+00	B(9)=	.24019248E-01	.2002E+00	.22666666E+02
B(1)	1	.52612154E+01	B(1)=	-.27655874E-01	-.5072E+00	.38216666E+02
B(8)	1	.43718914E+01	B(8)=	-.18256331E-01	-.4847E+00	.14348961E+03
B(22)	1	.12167614E+01	B(22)=	.32786628E+00	.2845E+00	.40534833E+01
B(24)	1	.20719976E+01	B(24)=	.91765132E+00	.3657E+00	.13791333E+01
		RSQ= .849215				
MODEL	5	.39463952E+01		R SQR = .84921566E+00		
ERROR	54	.64880629E-01				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 5

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.58835527E+01		.30007000E+01
B(1)	1	.79604843E+01	B(1)=	-.32855291E-01	-.6025E+00	.38216666E+02
B(8)	1	.46958610E+01	B(8)=	-.17658745E-01	-.4688E+00	.14348961E+03
B(15)	1	.50299048E+00	B(15)=	-.17458410E+00	-.1522E+00	.71545000E+00
B(24)	1	.20510993E+01	B(24)=	.74794759E+00	.2981E+00	.13791333E+01
		RSQ= .815892				
MODEL	4	.47394257E+01		R SQR = .81589285E+00		
ERROR	55	.77778672E-01				

REGRESSION ANALYSIS OF JOB 4, VARIABLE 6

SOURCE	DF	MEAN SQ		COEF	ST COEF	MEAN
TOTAL	59	.39382254E+00	B(0)=	.50770185E+01		.30007000E+01
B(3)	1	.31347259E+00	B(3)=	.11323547E-01	.1229E+00	.67061400E+02
B(1)	1	.75410524E+01	B(1)=	-.32159567E-01	-.5898E+00	.38216666E+02
B(8)	1	.42265001E+01	B(8)=	-.16952516E-01	-.4501E+00	.14348961E+03
B(15)	1	.40621703E+00	B(15)=	-.15802187E+00	-.1377E+00	.71545000E+00
B(24)	1	.16141872E+01	B(24)=	.68079472E+00	.2713E+00	.13791333E+01
		RSQ= .829383				
MODEL	5	.38542350E+01		R SQR = .82938392E+00		
ERROR	54	.73413981E-01				

```
VERIFICATION OF THE STEPWISE PROCEDURE BY ALTERNATE PROG.

PREDICTION EQUATION FOR THE ACTIVE GROUP

NOT REQURING GAS ANALYSIS

STEP NO.  1
VARIABLE ENTERING  1
F LEVEL = 21.2530
STANDARD ERROR OF Y = .4155E+00
COEFF OF DETERMINATION =  .38464E+00
MULTIPLE CORLTN COEFF =  .6202E+00
CONSTANT TERM =  .436432E+01
VARIABLE NO.      COEFFICIENT          STD ERR OF COEFF
    X-  1        -.32637E-01             .70794E-02

STEP NO.  2
VARIABLE ENTERING    3
F LEVEL =   11.3100
STANDARD ERROR OF Y =  .3639E00
COEFF OF DETERMINATION =  .541715E00
MULTIPLE CORLTN COEFF =  .73601E+00

CONSTANT TERM =   .22458E+01
VARIABLE NO.      COEFFICIENT          STD ERR OF COEFF
   X-  1         -.29665E-01             .6264E-02
   X-   3         .2996E-01              .89102E-02

STEP  4
VARIABLE ENTERING   24
F LEVEL =  8.8737
STANDARD ERROR OF Y =   .2941E+00
COEFF OF DETERMINATION =  .7189E+00
MULTIPLE CORLTN COEFF =   .847906E+00

CONSTANT TERM  =   .4174404E+00
VARIABLE NO.      COEFFICIENT          STD ERR OF COEFF
   X-  1         -.3468E-01             .51903334E-02
   X-  3          .231047E-01           .736798E-02
   X-   6        -.144119E-01           .404618E-02
   X- 15         .49783E+00             .167121E+00

COMPLETED  4  STEPS OF REGRESSION
```

APPENDIX D

Variable codes used in this section

1	Age in years
2	Weight in kilograms
3	Fat free weight in kilograms
4	Respiratory Freq. 8-9 min
5	Minute ventilation 8-9 min
6	Oxygen uptake 8-9 min
7	Resp. Exch. Ratio 8-9 min
8	Heart rate 8-9 min
9	Respiratory freq. 1-2 min
10	Minute ventilation 1-2 min
11	Oxygen uptake 1-2 min
12	Resp. exch. ratio 1-2 min
13	Heart rate 1-2 min
14	Heart rate difference
15	Rate of change of resp. freq.
16	Rate of change of minute ventilation
17	Rate of change of oxygen uptake
18	Rate of change of resp. exch. ratio
19	Rate of change of heart rate
20	Per cent 02 8-9 min
21	Tidal volume 8-9 min
22	Per cent CO_2 8-9 min
23	Per cent 02 1-2 min
24	Tidal Volume 1-2 min
25	Per cent CO_2 1-2 min
26	Maximum oxygen uptake

INTERCORRELATIONS FOR THE TOTAL PREDICTION VARIABLES

5	2	1	1	1	.10000000E+01
5	2	1	1	2	-.22089417E-01
5	2	1	1	3	-.13010831E+00
5	2	1	1	4	.23167232E-01
5	2	1	1	5	.18648344E+00
5	2	1	1	6	-.15819571E+00
5	2	1	1	7	.17302545E+00
5	2	1	1	8	.16817053E+00
5	2	1	1	9	.10900791E+00
5	2	1	1	10	.98062577E-01
5	2	1	1	11	-.61154130E-01
5	2	1	1	12	-.11479111E+00
5	2	1	1	13	.19682927E+00
5	2	1	1	14	.83979698E-02
5	2	1	1	15	-.11393617E+00
5	2	1	1	16	.19451818E+00
5	2	1	1	17	-.15596415E+00
5	2	1	1	18	.29480842E+00
5	2	1	1	19	.83999386E-02
5	2	1	1	20	-.27562834E+00
5	2	1	1	21	.15647841E+00
5	2	1	.	22	-.32625416E+00
5	2	1	1	23	-.13752010E+00
5	2	1	1	24	-.64476132E-01
5	2	1	1	25	-.28683376E+00
5	2	1	1	26	-.68332838E+00
5	2	1	2	2	.10000000E+01
5	2	1	2	3	.90936443E+00
5	2	1	2	4	.58114219E-01
5	2	1	2	5	.32784086E+00
5	2	1	2	6	.55099594E+00
5	2	1	2	7	.17748591E+00
5	2	1	2	8	-.68246868E-01
5	2	1	2	9	.89915030E-01
5	2	1	2	10	.25146143E+00
5	2	1	2	11	.42534639E+00
5	2	1	2	12	-.18172010E+00
5	2	1	2	13	-.22826598E-01
5	2	1	2	14	-.90827136E-01
5	2	1	2	15	-.35136590E-01
5	2	1	2	16	.27504129E+00
5	2	1	2	17	.16578298E+00
5	2	1	2	18	.35883186E+00
5	2	1	2	19	-.90785046E-01
5	2	1	2	20	.36686238E-01
5	2	1	2	21	.27461630E+00
5	2	1	2	22	.86841568E-01
5	2	1	2	23	.20438827E+00
5	2	1	2	24	.19215915E+00
5	2	1	2	25	.16359662E+00

```
5    2   1   2  26   .16506770E+00
5    2   1   3   3   .10000000E+01
5    2   1   3   4  -.46823916E-01
5    2   1   3   5   .18680576E+00
5    2   1   3   6   .55389503E+00
5    2   1   3   7   .51665954E-01
5    2   1   3   8  -.18828814E+00
5    2   1   3   9   .51512379E-01
5    2   1   3  10   .24348571E+00
5    2   1   3  11   .46986010E+00
5    2   1   3  12  -.16576698E+00
5    2   1   3  13  -.73258657E-01
5    2   1   3  14  -.23478147E+00
5    2   1   3  15  -.14096232E+00
5    2   1   3  16   .71911200E-01
5    2   1   3  17   .91559739E-01
5    2   1   3  18   .21209018E+00
5    2   1   3  19  -.23474032E+00
5    2   1   3  20   .19779447E+00
5    2   1   3  21   .25924233E+00
5    2   1   3  22   .25706819E+00
5    2   1   3  23   .27148965E+00
5    2   1   3  24   .22268989E+00
5    2   1   3  25   .26269803E+00
5    2   1   3  26   .36427889E+00
5    2   1   4   4   .10000000E+01
5    2   1   4   5   .65240590E+00
5    2   1   4   6   .17268734E+00
5    2   1   4   7   .52187204E+00
5    2   1   4   8   .42848441E+00
5    2   1   4   9   .76219215E+00
5    2   1   4  10   .53619957E+00
5    2   1   4  11   .13563356E+00
5    2   1   4  12   .19466988E+00
5    2   1   4  13   .36897667E+00
5    2   1   4  14   .22439312E+00
5    2   1   4  15   .46701773E+00
5    2   1   4  16   .51690409E+00
5    2   1   4  17   .44722622E-01
5    2   1   4  18   .35556159E+00
5    2   1   4  19   .22430237E+00
5    2   1   4  20  -.68554843E+00
5    2   1   4  21  -.49353034E+00
5    2   1   4  22  -.67531708E+00
5    2   1   4  23  -.52901044E+00
5    2   1   4  24  -.49391511E+00
5    2   1   4  25  -.55594338E+00
5    2   1   4  26  -.43770555E+00
5    2   1   5   5   .10000000E+01
5    2   1   5   6   .59188358E+00
```

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5    2   1   5   7   .74757101E+00
5    2   1   5   8   .59878205E+00
5    2   1   5   9   .57220524E+00
5    2   1   5  10   .76658227E+00
5    2   1   5  11   .46937983E+00
5    2   1   5  12   .21234449E+00
5    2   1   5  13   .57071113E+00
5    2   1   5  14   .22918715E+00
5    2   1   5  15   .20250720E+00
5    2   1   5  16   .83919090E+00
5    2   1   5  17   .15194444E+00
5    2   1   5  18   .57170396E+00
5    2   1   5  19   .22914017E+00
5    2   1   5  20  -.69164803E+00
5    2   1   5  21   .29661782E+00
5    2   1   5  22  -.62917994E+00
5    2   1   5  23  -.36285157E+00
5    2   1   5  24   .85915924E-01
5    2   1   5  25  -.33059391E+00
5    2   1   5  26  -.41303052E+00
5    2   1   6   6   .10000000E+01
5    2   1   6   7   .22927118E+00
5    2   1   6   8   .34152373E+00
5    2   1   6   9   .27156541E+00
5    2   1   6  10   .57143835E+00
5    2   1   6  11   .83445824E+00
5    2   1   6  12  -.20642952E+00
5    2   1   6  13   .29759184E+00
5    2   1   6  14   .17349298E+00
5    2   1   6  15  -.11046069E+00
5    2   1   6  16   .39699992E+00
5    2   1   6  17   .18695683E+00
5    2   1   6  18   .44255442E+00
5    2   1   6  19   .17353000E+00
5    2   1   6  20   .99939722E-01
5    2   1   6  21   .40444001E+00
5    2   1   6  22   .17627613E+00
5    2   1   6  23   .38170368E+00
5    2   1   6  24   .27964806E+00
5    2   1   6  25   .38967666E+00
5    2   1   6  26   .12295286E+00
5    2   1   7   7   .10000000E+01
5    2   1   7   8   .58419646E+00
5    2   1   7   9   .32022046E+00
5    2   1   7  10   .40295123E+00
5    2   1   7  11   .82256229E-01
5    2   1   7  12   .51182213E+00
5    2   1   7  13   .52750577E+00
5    2   1   7  14   .26847139E+00
5    2   1   7  15   .34989658E+00
```

```
5    2   1   7  16   .77140528E+00
5    2   1   7  17   .23454058E+00
5    2   1   7  18   .54590436E+00
5    2   1   7  19   .26844977E+00
5    2   1   7  20  -.71276225E+00
5    2   1   7  21   .18832658E+00
5    2   1   7  22  -.49796573E+00
5    2   1   7  23  -.42931137E+00
5    2   1   7  24  -.85073617E-02
5    2   1   7  25  -.23982783E+00
5    2   1   7  26  -.44160275E+00
5    2   1   8   8   .10000000E+01
5    2   1   8   9   .32365817E+00
5    2   1   8  10   .46987322E+00
5    2   1   8  11   .34720908E+00
5    2   1   8  12   .26672477E+00
5    2   1   8  13   .84002561E+00
5    2   1   8  14   .55601853E+00
5    2   1   8  15   .20428638E+00
5    2   1   8  16   .49322604E+00
5    2   1   8  17  -.47968183E-01
5    2   1   8  18   .35464933E+00
5    2   1   8  19   .55601873E+00
5    2   1   8  20  -.46587980E+00
5    2   1   8  21   .81567707E-01
5    2   1   8  22  -.34394410E+00
5    2   1   8  23  -.96305991E-01
5    2   1   8  24   .26187228E-01
5    2   1   8  25   .38894310E-01
5    2   1   8  26  -.59350267E+00
5    2   1   9   9   .10000000E+01
5    2   1   9  10   .74808880E+00
5    2   1   9  11   .40890444E+00
5    2   1   9  12   .10683585E+00
5    2   1   9  13   .39054607E+00
5    2   1   9  14  -.18346304E-02
5    2   1   9  15  -.21646054E+00
5    2   1   9  16   .21810209E+00
5    2   1   9  17  -.27612452E+00
5    2   1   9  18   .23300750E+00
5    2   1   9  19  -.18818519E-02
5    2   1   9  20  -.47836711E+00
5    2   1   9  21  -.29043154E+00
5    2   1   9  22  -.49778414E+00
5    2   1   9  23  -.42915278E+00
5    2   1   9  24  -.53117185E+00
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INTERCORRELATION FOR THE ACTIVE PREDICTION GROUP

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INTERCORRELATION FOR THE INACTIVE PREDICTION GROUP

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```
5     2   1  24  24   .10000001E+01
5     2   1  24  25   .23085094E+00
5     2   1  24  26   .12287590E+00
5     2   1  25  25   .10000000E+01
5     2   1  25  26   .50054882E+00
5     2   1  26  26   .10000000E+01
```

Variable codes used in this section

1	Age in years
2	Weight in kilograms
3	Fat free weight in kilograms
4	Respiratory Freq. 8-9 min
5	Minute ventilation 8-9 min
6	Oxygen uptake 8-9 min
7	Resp. Exch. Ratio 8-9 min
8	Heart rate 8-9 min
9	Respiratory freq. 1-2 min
10	Minute ventilation 1-2 min
11	Oxygen uptake 1-2 min
12	Resp. exch. ratio 1-2 min
13	Heart rate 1-2 min
14	Heart rate difference
15	Rate of change of resp. freq.
16	Rate of change of minute ventilation
17	Rate of change of oxygen uptake
18	Rate of change of resp. exch. ratio
19	Rate of change of heart rate
20	Per cent 02 8-9 min
21	Tidal volume 8-9 min
22	Per cent CO_2 8-9 min
23	Per cent 02 1-2 min
24	Tidal Volume 1-2 min
25	Per cent CO_2 1-2 min
26	Maximum oxygen uptake

TOTAL PREDICTION GROUP

					MEAN	STD. DEV.
3	2	1	1	.22930000E+04	.38216666E+02	.11509896E+02
3	2	1	2	.47621700E+04	.79369500E+02	.85196781E+01
3	2	1	3	.40236840E+04	.67061400E+02	.68128990E+01
3	2	1	4	.16606200E+04	.27677000E+02	.57774693E+01
3	2	1	5	.30499250E+04	.50832083E+02	.11079305E+02
3	2	1	6	.11729800E+03	.19549666E+01	.24147674E+00
3	2	1	7	.61628000E+02	.10271333E+01	.67084944E-01
3	2	1	8	.86093770E+04	.14348961E+03	.16662858E+02
3	2	1	9	.13600000E+04	.22666666E+02	.52324524E+01
3	2	1	10	.18353290E+04	.30588816E+02	.63039629E+01
3	2	1	11	.75017000E+02	.12502833E+01	.25720956E+00
3	2	1	12	.51314000E+02	.85523333E+00	.62998385E-01
3	2	1	13	.66720000E+04	.11120000E+03	.13851267E+02
3	2	1	14	.19373290E+04	.32288816E+02	.90416746E+01
3	2	1	15	.42927000E+02	.71545000E+00	.54711884E+00
3	2	1	16	.17348400E+03	.28914000E+01	.10634307E+01
3	2	1	17	.60080000E+01	.10013333E+00	.20533131E-01
3	2	1	18	.14390000E+01	.23983333E-01	.92818247E-02
3	2	1	19	.27674200E+03	.46123666E+01	.12916655E+01
3	2	1	20	.23616900E+03	.39361500E+01	.72404899E+00
3	2	1	21	.11293300E+03	.18822166E+01	.39928961E+00
3	2	1	22	.24320900E+03	.40534833E+01	.54455859E+00
3	2	1	23	.24799500E+03	.41332500E+01	.66585868E+00
3	2	1	24	.82748000E+02	.13791333E+01	.25014673E+00
3	2	1	25	.21238100E+03	.35396833E+01	.43410456E+00
3	2	1	26	.18004200E+03	.30007000E+01	.62755281E+00

ACTIVE PREDICTION GROUP

					MEAN	STD. DEV.
3	2	1	1	.12190000E+04	.33861111E+02	.99201180E+01
3	2	1	2	.28244300E+04	.78456388E+02	.86597426E+01
3	2	1	3	.24242170E+04	.67339361E+02	.69737671E+01
3	2	1	4	.98300000E+03	.27305555E+02	.54971160E+01
3	2	1	5	.16924940E+04	.47013722E+02	.67914420E+01
3	2	1	6	.69093000E+02	.19192500E+01	.24915112E+00
3	2	1	7	.36026000E+02	.10007222E+01	.53573713E-01
3	2	1	8	.48990000E+04	.13608333E+03	.12652238E+02
3	2	1	9	.83200000E+03	.23111111E+02	.50977753E+01
3	2	1	10	.10718330E+04	.29773138E+02	.48958057E+01
3	2	1	11	.43935000E+02	.12204166E+01	.24300629E+00
3	2	1	12	.30789000E+02	.85525000E+00	.86616890E-01
3	2	1	13	.38020000E+04	.10561111E+03	.12119122E+02
3	2	1	14	.10979730E+04	.30499250E+02	.86205684E+01
3	2	1	15	.21559000E+02	.59886111E+00	.47273601E+00
3	2	1	16	.88669000E+02	.24630277E+01	.83102329E+00
3	2	1	17	.35770000E+01	.99361111E-01	.24413292E-01
3	2	1	18	.72800000E+00	.20222222E-01	.11092111E-01
3	2	1	19	.15684500E+03	.43568055E+01	.12315160E+01
3	2	1	20	.14855000E+03	.41263888E+01	.57802792E+00
3	2	1	21	.64023000E+02	.17784166E+01	.37626282E+00
3	2	1	22	.14911900E+03	.41421944E+01	.45846077E+00
3	2	1	23	.14846900E+03	.41241388E+01	.67943800E+00
3	2	1	24	.48058000E+02	.13349444E+01	.30353681E+00
3	2	1	25	.12664200E+03	.35178333E+01	.40118787E+00
3	2	1	26	.11733100E+03	.32591944E+01	.52202708E+00

INACTIVE PREDICTION GROUP

					MEAN	STD. DEV.
3	2	1	1	.15010000E+04	.41694444E+02	.98729644E+01
3	2	1	2	.29673900E+04	.82427500E+02	.89096416E+01
3	2	1	3	.24704760E+04	.68624333E+02	.72843668E+01
3	2	1	4	.10406200E+04	.28906111E+02	.53827023E+01
3	2	1	5	.20050830E+04	.55696750E+02	.11338215E+02
3	2	1	6	.73320000E+02	.20366666E+01	.21862165E+00
3	2	1	7	.37664000E+02	.10462222E+01	.76240596E-01
3	2	1	8	.54313770E+04	.15087158E+03	.15394915E+02
3	2	1	9	.85200000E+03	.23666666E+02	.56213902E+01
3	2	1	10	.11730070E+04	.32583527E+02	.67830207E+01
3	2	1	11	.47829000E+02	.13285833E+01	.22967784E+00
3	2	1	12	.30600000E+02	.85000000E+00	.67128873E-01
3	2	1	13	.42300000E+04	.11750000E+03	.13990813E+02
3	2	1	14	.12013490E+04	.33370805E+02	.96342914E+01
3	2	1	15	.26933000E+02	.74813888E+00	.56096088E+00
3	2	1	16	.11885200E+03	.33014444E+01	.10826540E+01
3	2	1	17	.36220000E+01	.10061111E+00	.19213506E-01
3	2	1	18	.99100000E+00	.27527777E-01	.92008896E-02
3	2	1	19	.17161000E+03	.47669444E+01	.13763186E+01
3	2	1	20	.13382300E+03	.37173055E+01	.64511239E+00
3	2	1	21	.70393000E+02	.19553611E+01	.34431463E+00
3	2	1	22	.14063900E+03	.39066388E+01	.43217521E+00
3	2	1	23	.14928900E+03	.41469166E+01	.59000338E+00
3	2	1	24	.50434000E+02	.14009444E+01	.21251964E+00
3	2	1	25	.12715700E+03	.35321388E+01	.37482109E+00
3	2	1	26	.97982000E+02	.27217222E+01	.47110750E+00

```
   VARIABLE 1 IS THE OBSERVED MAXIMUM OXYGEN UPTAKE
   VARIABLE 2 IS PREDICTED UPTAKE FROM EQUATION REQUIRING GAS
   ANALYSIS
   VARIABLE 3 IS PREDICTED UPTAKE FROM EQUATION NOT REQUIRING
   GAS ANALYSIS
   INTERCORRELATION MATRIX FOR THE TOTAL TEST GROUP

 VAR     1     2     3
0 1   1.00
0 2    .56  1.00
0 3    .51   .96  1.00
                          MEAN            STD.          NO. SUBJ.
          VARIABLE( 1)    3.32             .44             28
          VARIABLE( 2)    3.50             .46             28
          VARIABLE( 3)    3.48             .45             28
   INTERCORRELATION FOR THE ACTIVE TEST GROUP
   VARIABLE SET UP THE SAME AS ABOVE
 VAR     1     2     3
0 1   1.00
0 2    .81  1.00
0 3    .67   .80  1.00
                          MEAN            STD.          NO. SUBJ.
          VARIABLE( 1)    3.63             .32             15
          VARIABLE( 2)    3.67             .35             15
          VARIABLE( 3)    3.63             .34             15
   INTERCORRELATION FOR THE INACTIVE TEST GROUP
   VARIABLE SET UP THE SAME AS ABOVE
 VAR     1     2     3
0 1   1.00
0 2    .71  1.00
0 3    .55   .72  1.00
                          MEAN            STD.          NO. SUBJ.
          VARIABLE( 1)    2.96             .25             13
          VARIABLE( 2)    2.92             .33             13
          VARIABLE( 3)    2.89             .30             13
1 THIS IS THE EQUATION SPECIFIC SET UP
 VAR     1     2     3
0 1   1.00
0 2    .90  1.00
0 3    .85   .90  1.00
                          MEAN            STD.          NO. SUBJ.
          VARIABLE( 1)    3.32             .44             28
          VARIABLE( 2)    3.32             .51             28
          VARIABLE( 3)    3.28             .49             28
 ALL DATA PROCESSED
```

INTERCORRELATION FOR REPRODUCIBILITY STUDY

VARIABLE 2 IS TEST 1

VARIABLE 4 IS TEST 2

1 THIS IS ,. TEST RETEST R

VAR	1	2	3	4
0 1	1.00			
0 2	.78	1.00		
0 3	.93	.84	1.00	
0 4	.85	.91	.94	1.00

	MEAN	STD.	NO. SUBJ.
VARIABLE(1)	3.48	.36	12
VARIABLE(2)	3.45	.45	12
VARIABLE(3)	3.44	.47	12
VARIABLE(4)	3.44	.50	12

VARIABLE 2 FOR THIS SECTION IMPLIES PREDICTION EQUATION REQUIRING GAS ANALYSIS IS BEING COMPARED TO THE OBSERVED MAXIMUM OXYGEN UPTAKE
VARIABLE 3 IMPLIES THAT THE EQUATION NOT REQUIRING GAS ANALYSIS IS BEING COMPARED TO THE OBSERVED MAXIMUM OXYGEN UPTAKES

TOTAL PREDICTION EQUATION T-TEST

VAR(2) MEAN DIFF = -.184 S.D. OF DIFF = .421 T = -2.312
VAR(3) MEAN DIFF = -.165 S.D. OF DIFF = .438 T = -1.996

ACTIVE PREDICTION EQUATION T-TESTS

VAR(2) MEAN DIFF = -.041 S.D. OF DIFF = .205 T = -.776

VAR(3) MEAN DIFF = 0.000 S.D. OF DIFF = .267 T = .006

INACTIVE PREDICTION EQUATION T-TESTS

VAR(2) MEAN DIFF = .042 S.D. OF DIFF = .233 T = .647

VAR(3) MEAN DIFF = .071 S.D. OF DIFF = .262 T = .985

COMPOSITE PREDICTION EQUATION T-TESTS

VAR(2) MEAN DIFF = -.002 S.D. OF DIFF = .218 T = -.061

VAR(3) MEAN DIFF = .033 S.D. OF DIFF = .263 T = .676

THIS IS A T-TEST FOR REPRODUCIBILITY STUDY

VAR(2) MEAN DIFF = .043 S.D. OF DIFF = .190 T = .792

IN THE COURSE OF INVESTIGATING THE PREDICTION FROM SLOPES OF SEVERAL SUBMAXIMUM PARAMETERS

A COMPUTER PROGRAMME WAS CONSTRUCTED

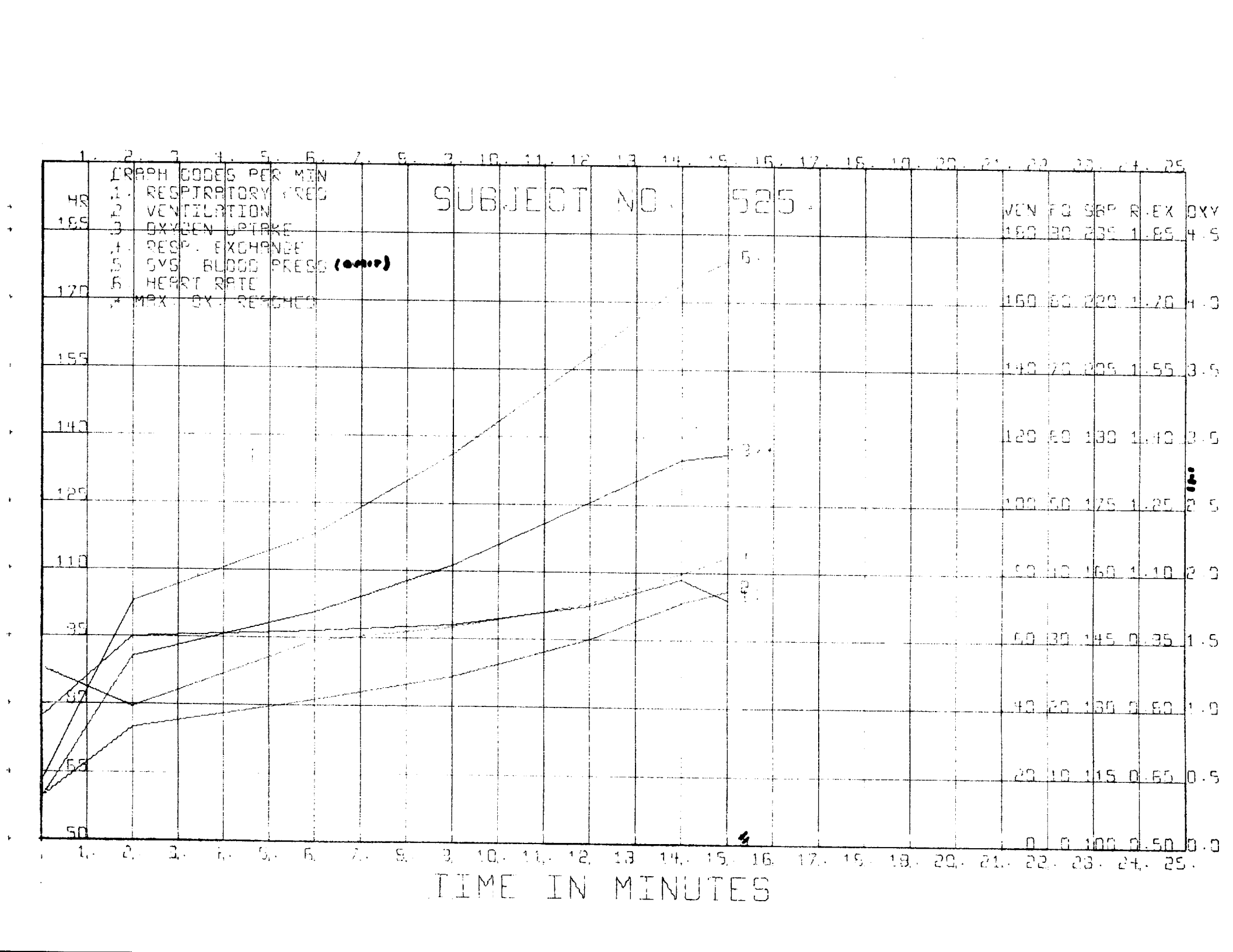
TO PLOT THE SUBMAXIMUM VARIABLES

ON A COMMON GRAPH TO LOOK AT DATA TRENDS

THE GRAPH ON THE FOLLOWING PAGE IS PREPRESENTIVE

OF THIS INVESTIGATION

ALL GRAPH CODES ARE LISTED ON THE GRAPH.


SUBJECT NO. 525.
GRAPH CODES PER MIN
1. RESPIRATORY FREQ
2. VENTILATION
3. OXYGEN UPTAKE
4. RESP. EXCHANGE
5. SYS. BLOOD PRESS
6. HEART RATE
7. MAX. OX. RESPIRES
HR
VEN FQ SBP R.EX OXY
TIME IN MINUTES

APPENDIX E

THE TOTAL PREDICTION EQUATION RESULTS

THE FIRST PREDICTED VALUE IS BASED ON EQUATION

REQUIRING GAS ANALYSIS

THE SECOND DOES NOT REQUIRE GAS ANALYSIS

THE DIFFERENCES ARE BETWEEN OBSERVED AND PREDICTED

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
3.926	3.260	-.665	3.167	-.758	1120
3.548	3.677	.129	3.591	.043	1121
3.689	3.755	.066	3.690	.001	1122
3.448	3.450	.002	3.560	.112	1123
3.737	3.584	-.152	3.533	-.203	1124
3.733	3.886	.153	3.663	-.069	1125
3.566	3.787	.221	3.897	.331	1129
4.200	4.189	-.010	4.099	-.100	2110
3.791	3.477	-.313	3.454	-.336	2111
3.110	3.547	.437	3.496	.386	2112
3.965	4.704	.739	4.703	.738	2113
3.873	3.686	-.186	3.633	-.239	1142
3.165	3.743	.578	3.330	.165	2116
3.556	3.826	.270	3.723	.167	2115
3.096	3.462	.366	3.463	.367	2114
3.058	2.936	-.121	3.072	.014	3101
2.965	2.816	-.148	2.892	-.072	3102
2.934	3.898	.964	3.885	.951	3103
2.776	2.748	-.027	2.705	-.070	3104
2.416	3.015	.599	2.896	.480	3105
3.049	2.901	-.147	2.923	-.125	3106
2.535	3.509	.974	3.576	1.041	3107
3.261	3.074	-.186	3.133	-.127	3108
3.149	3.750	.601	3.779	.630	3145
3.019	3.588	.569	3.557	.538	3143
3.172	2.661	-.510	2.626	-.545	3141
3.072	3.690	.618	3.847	.775	3150
3.088	3.440	.352	3.636	.548	3151

THE ACTIVL PREDICTION EQUATION RESULTS

THE FIRST PREDICTED VALUE IS BASED ON EQUATION

REQUIRING GAS ANALYSIS

THE SECOND DOES NOT REQUIRE GAS ANALYSIS

THE DIFFERENCES ARE BETWEEN OBSERVED AND PREDICTED

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
3.791	3.752	-.038	3.490	-.300	2111
3.110	3.331	.221	3.272	.162	2112
3.965	4.142	.177	4.468	.503	2113
3.873	4.110	.237	3.601	-.271	1142
3.165	3.262	.097	3.312	.147	2116
3.556	3.701	.145	3.694	.138	2115
3.096	3.139	.043	3.425	.329	2114
3.926	3.429	-.496	3.416	-.509	1120
3.548	3.412	-.135	3.309	-.238	1121
3.689	3.709	.020	3.503	-.185	1122
3.448	3.406	-.041	3.388	-.059	1123
3.737	3.604	-.132	3.850	.113	1124
4.200	4.306	.106	4.188	-.011	2110
3.733	3.769	.036	3.710	-.022	1125
3.566	3.948	.382	3.770	.204	1129

THE INACTIVE PREDICTION EQUATION RESULTS

THE FIRST PREDICTED VALUE IS BASED ON EQUATION REQUIRING GAS ANALYSIS
THE SECOND DOES NOT REQUIRE GAS ANALYSIS

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
3.058	2.561	-.496	2.544	-.513	3101
2.965	2.723	-.241	2.560	-.404	3102
2.934	3.115	.181	3.147	.213	3103
2.776	2.378	-.397	2.530	-.245	3104
2.416	2.448	.032	2.552	.136	3105
3.049	2.976	-.072	2.765	-.283	3106
2.535	2.697	.162	2.738	.203	3107
3.261	3.356	.095	2.967	-.293	3108
3.149	2.884	-.264	3.437	.288	3145
3.019	3.117	.098	3.175	.156	3143
3.172	3.320	.148	3.214	.042	3141
3.072	3.267	.195	2.963	-.108	3150
3.088	3.106	.018	2.968	-.119	3151

REPRODUCIBILITY DATA

TWO CARDS PER SUBJECT (TEST 1 AND TEST 2)

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
3.548	3.259	-.288	3.280	-.267	1921
3.548	3.412	-.135	3.309	-.238	8121
3.689	3.648	-.040	3.430	-.258	1922
3.689	3.709	.020	3.503	-.185	8122
3.015	3.477	.462	3.308	.293	2909
3.015	3.658	.643	3.455	.440	8109
4.253	3.551	-.701	3.618	-.634	8118
4.253	3.551	-.701	3.618	-.634	8118
4.200	4.343	.143	4.151	-.048	2910
4.200	4.306	.106	4.188	-.011	8110
3.110	3.563	.453	3.406	.296	2912
3.110	3.331	.221	3.272	.162	8112
3.096	3.228	.132	3.717	.621	2914
3.096	3.139	.043	3.425	.329	8114
3.165	3.308	.143	3.392	.227	2916
3.165	3.262	.097	3.312	.147	2116
3.701	3.933	.232	4.190	.489	2913
3.701	4.142	.441	4.468	.767	8113
3.058	3.164	.106	3.185	.127	3901
3.058	2.905	-.152	2.996	-.061	8101
2.965	3.155	.190	2.509	-.455	3902
2.965	2.723	-.241	2.560	-.404	8102
2.934	3.148	.214	3.223	.289	3903
2.934	3.115	.181	3.147	.213	8103

THE PREDICTION GROUP OF 60 FROM THE APPROPRIATE ACTIVITY RELATED EQUATIONS

THE FIRST PREDICTED VALUE IS BASED ON EQUATION REQUIRING GAS ANALYSIS

THE SECOND DOES NOT REQUIRE GAS ANALYSIS

THE DIFFERENCES ARE BETWEEN OBSERVED AND PREDICTED

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
2.911	2.932	.021	2.931	.020	22
2.597	2.555	-.041	2.552	-.044	23
2.543	2.501	-.041	2.764	.221	24
2.600	2.359	-.240	2.571	-.028	101
2.485	2.400	-.084	2.465	-.019	86
2.489	2.520	.031	2.830	.341	85
2.376	2.588	.212	2.556	.180	82
1.821	1.379	-.441	1.573	-.247	54
2.717	2.344	-.372	2.718	.001	55
2.222	2.023	-.198	2.411	.189	41
3.058	3.058	0.000	3.278	.220	42
2.867	2.778	-.088	2.773	-.093	45
2.066	2.073	.007	2.269	.203	64
2.031	2.207	.176	2.486	.455	66
2.574	2.448	-.125	2.593	.019	104
2.236	1.976	-.259	2.253	.017	53
2.789	2.473	-.315	2.769	-.019	61
2.562	2.414	-.147	2.405	-.156	56
2.409	2.400	-.008	2.647	.238	83
2.673	2.215	-.457	2.630	-.042	84
2.399	2.163	-.235	2.221	-.177	81
2.957	3.118	.161	2.964	.007	46
2.561	2.241	-.319	2.443	-.117	65
1.820	2.069	.249	1.908	.088	63
3.172	3.781	.609	3.803	.631	943

OBSERVED	PRED.	DIFF	PRED.	DIFF	I.D.
3.583	3.146	-.436	3.084	-.498	51
3.227	3.453	.226	3.408	.181	25
3.335	3.160	-.174	3.382	.047	103
2.533	2.540	.007	2.690	.157	62
2.533	2.850	.317	2.858	.325	106
3.352	3.597	.245	3.740	.388	21
3.391	3.635	.244	3.511	.120	105
2.871	2.766	-.104	2.724	-.146	52
3.274	3.226	-.047	3.514	.240	43
3.474	3.542	.068	3.493	.019	44
3.474	3.407	-.066	3.413	-.060	26
2.672	2.578	-.093	2.732	.060	93
3.417	3.289	-.127	3.237	-.179	12
3.808	3.627	-.180	3.491	-.316	15
3.602	3.297	-.304	3.324	-.277	16
3.103	3.071	-.031	3.048	-.054	33
3.104	3.194	.090	3.315	.211	32
3.256	3.207	-.048	3.125	-.130	34
3.375	3.582	.207	3.574	.199	73
3.493	3.566	.073	3.730	.237	74
3.844	3.863	.019	3.617	-.226	76
2.001	2.339	.338	2.339	.338	91
2.407	2.806	.399	2.733	.326	92
2.658	2.983	.325	3.133	.475	31
2.940	2.993	.053	3.030	.090	94
2.699	2.873	.174	2.789	.090	95
2.780	2.712	-.067	2.406	-.373	94
3.022	2.551	-.470	2.578	-.443	35
3.341	3.083	-.257	3.060	-.280	36
3.558	3.428	-.129	3.503	-.054	75
4.094	3.914	-.179	3.732	-.361	71
4.530	4.368	-.161	4.171	-.358	13
3.700	3.347	-.352	3.534	-.165	14
3.566	3.376	-.189	3.518	-.047	72
4.142	4.140	-.001	3.989	-.152	936

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