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PREDICTION OF MAXIMUM OXYGEN UPTAKE IN PARAPLEGICS AND QUADRAPLEGICS USING MULTIPLE REGRESSION EQUATIONS

by

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ABSTRACT

Twenty physically disabled subjects performed a progressive continuous exercise protocol on a wheelchair ergometer, to maximum exertion. Cardiorespiratory responses were monitored by means of direct ECG recording, and HR was reported for the last 30 seconds of each workload (WL).

Expired gases were continuously sampled and analyzed for 15 second determinations of respiratory gas exchange variables. The last 30 seconds at each WL was averaged and assumed to be representative of steady state responses to that WL. In addition, body weights, ages, and maximum breathing capacities were recorded. Two subjects were deleted from the study due to incomplete data.

The inability to equate structural and functional characteristics of quadraplegics and paraplegics necessitated the division of the total group into paraplegics (N=13) and quadraplegics (N=5).

For each paraplegic subject, three submaximal WL and corresponding cardiorespiratory responses were chosen for multiple regression analysis on maximal oxygen uptake. The three workloads were selected on the basis of HR responses, i.e., those workloads where HR was found to be between 65% and 85% of maximum HR (max HR = 220 - age). The lowest of the three workloads and corresponding cardiorespiratory responses (CRR) for each subject were assigned to the LHR group while the highest workloads and CRR for each were assigned to the HHR group. The remaining WL and CRR for each subject was assigned to the MHR group. Mean HR responses for the

LHR, MHR, and HHR groups were: 131, 139, and 148, respectively. These means corresponded to approximately 70%, 75%, and 80% of maximum heart rate.

The squared multiple correlation coefficients (R^2) adjusted for both sample size and number of variables contributing to R^2, were found to be .8761, .9218, and .9094 for LHR, MHR, and HHR, respectively. The respective standard error of estimates were reported to be .1397, .1101, and .1195 or $\pm$ CV% equal to 6.5%, 5.2%, and 5.6%.

Cross validation was not performed due to the small sample size. However, the adjusted press prediction gives an indication of how the equation may predict for subjects outside the experimental group. Prediction is performed in turn for each subject with the effects of that subject's data removed from the beta coefficients. The mean absolute errors reported were 22.2%, 11.8%, and 13.2% for the LHR, MHR, and HHR groups, respectively.

Multiple regression analysis of the quadraplegic data was restricted to the WL and CRR at the fourth minute of the progressive continuous workload protocol. The adjusted R^2 for the prediction equation produced was .9992 with a standard error of estimate of .0058 L/min. The variables contributing to the R^2 were: Ventilation, VO2 ml/kg min., and WL.

It was concluded that:

1. Multiple regression analysis appeared to be a suitable method of developing accurate prediction equations for MVO2 L/min., in paraplegics. The best equation being:

   MVO2 L/min. = 5.85 + 1.70(VCO2 L/min.) - .026(age) - .0015(WL) - .008(HR) - 3.42(RQ).

2. The accuracy of prediction of MVO2 L/min. in paraplegics is increased with the increase in the physiological stress (as reflected in % maximum HR).

3. Due to the limited sample size, no conclusions were reached regarding prediction of MVO2 L/min. within the quadraplegic population.

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CHAPTER I

INTRODUCTION

Several studies have directly assessed the maximum aerobic capacities of paraplegics and quadraplegics (Knutsson et al., 1973; Zwiren and Bar-or, 1975; Wicks et al., 1977; Cameron et al., 1977; Emes, 1977; Hjeltnes, 1977). Unfortunately, the data tells us little about the cardiorespiratory "fitness" of the individuals. Without norms, interpretations are limited. The data obtained by the investigations listed above, represent only a sub-population, i.e., those capable and motivated enough to perform exercise to maximum oxygen uptake.

The results obtained from investigations (Heigenhauser et al., 1977; Zwiren and Bar-or, 1975) indicated that cardiorespiratory capacities of the inactive paraplegics are significantly lower than sedentary normals. This information supports the concern expressed by other investigators who have indicated a need to monitor the cardiorespiratory fitness of the physically disabled (Hjeltnes, 1977; Engel & Hilderbrandt, 1973; Marincek et al., 1977; Knutsson et al., 1973).

For such tests to be suitable for the physically disabled population, the following criteria are suggested:

1. The test should be submaximal in nature. Although indications are that paraplegics and quadraplegics who are stabilized, can perform maximal tests, the usefulness of such tests is limited to this stabilized segment of the population. During the rehabilitation stage, aerobic testing

would prove extremely valuable. However, maximum exertion is ill advised since the subjects are not stabilized and prone to dizziness and fainting. In addition, maximum exertion is not recommended for the elderly.

2. The test should be easy to administer and its duration relatively short so that large population studies will not be overly laborious.
3. The test should be valid and reliable in its prediction of maximum oxygen uptake.

Direct assessment methods do not meet the first two criteria above. Thus, indirect methods are considered to be more practical for the purpose of cardiorespiratory fitness assessment with the physically disabled population. Several indirect tests for the prediction of maximum oxygen uptake are available to the normal population. A summary of the predictive capacities of each is provided in Table 1 (page 15).

The most widely used indirect tests are those which employ extrapolation of the plot of heart rate vs. oxygen uptake (Astrand & Ryhming, 1954; Margaria et al., 1965; Maritz et al., 1961). Serious problems exist with these methods. Most of the problems can be ascribed to three basic assumptions incorporated into the extrapolation methods. These are as follows:

1. A linear relationship exists between heart rate and oxygen uptake, at all levels of work.
2. There is one maximum heart rate value for all members of a given population.
3. The mechanical efficiency for all subjects is about 23% (where VO2 for submaximum workloads is not measured directly).

The validity of assumptions 1 and 2 has been questioned by several investigators (Maritz et al., 1961; Flandrois & LaCour, 1971; Davies, 1968; Glassford et al., 1965; Wyndham, 1967; Wyndham, 1959; Rowell et al., 1964). A coefficient of variation of about 4-5% in mechanical efficiency is reported (Shephard, 1977). Error of up to 20% (Hermiston & Faulkner, 1971) can be ascribed to violation of one or more of these basic assumptions.

The unsatisfactory results obtained using the extrapolation, has led to the investigation of a large number of variables and their relationships to maximum oxygen uptake. Investigators have attempted to improve prediction by incorporating more variables into the prediction procedure. This is accomplished through multiple regression analysis and multiple regression equations (Hermiston & Faulkner, 1971; Mastropaolo, 1970; Bonen et al., 1979; Fox, 1973; Jessup et al., 1974; Jette et al., 1976; Bell & Hinson, 1974). Table 1 summarizes the majority of the results of these investigations. The variability in maximum HR found within the paraplegic population, as well as the lack of information relating other physiological variables during exercise, suggests that extrapolation may not prove a viable method of predicting MVO2L. Multiple regression appears to be most suitable for the development of maximum oxygen uptake prediction tests with the physically disabled.

Statement of the Problem

The purpose of this investigation is to determine which of certain structural and functional measures of physically disabled subjects (predictors) are significantly related to maximum oxygen uptake (criterion) and to establish the greatest multiple correlation coefficient between the predictors and the criterion.

Subproblem

To construct a multiple regression equation for the prediction of maximum oxygen uptake.

Justification

At present, no indirect cardiorespiratory fitness test is available for use with the physically disabled population. Direct tests require elaborate testing equipment, maximum effort from the subjects, and considerable time to administer. Population studies are not practical with these direct methods. In addition, direct methods are not recommended for unstabilized subjects nor for the elderly. In contrast, indirect tests require little equipment, take approximately six minutes to complete and only submaximal efforts from the subjects.

Information regarding physiological changes, as a result of bed rest, a training regime, or rehabilitation procedures, can be made available through repeated testing. This feedback is extremely important when monitoring an individual's rehabilitation, to assist in further exercise prescription and as a motivational factor for the subject.

Limitations

1. The results of the multiple regression analysis of the data collected on the thirteen paraplegic subjects may be inferred to subjects within the age range and level of spinal lesion associated with the sample investigated in the present study.
2. The small sample size of the quadraplegic group, does not allow justified inference to the population outside the experimental group.
3. The assumptions associated with the protocol for workload adjustments, i.e., the final 30 seconds at each workload (duration one minute)

represents a steady state.

4. The equation(s) developed for the prediction of MVO2L do not constitute a "fitness test." MVO2L indicates aerobic power. In addition, cross validation was not performed.

Delimitations

The present study is delimited to:

1. male paraplegics and quadraplegics between the ages of 18 to 53
2. the variables (predictors) submitted to regression analysis
3. the wheelchair ergometer constructed for workload variations
4. the Pearson-product-moment correlation analysis
5. the method of expression of aerobic capacity, i.e., MVO2L.

Definitions

1. Stabilized: A post rehabilitated state in which the subject's cardiovascular system has been returned to a state which reduces the chance of the orthostatic reaction. This is accomplished via an increase in constrictory vasomotor tone in the vessels serving the immobilized segments of the body.
2. Orthostatic reaction: A condition resulting from a loss of tone in blood vessels serving the upper and/or lower limbs. The condition may be further compounded by loss of the sympathetic innervation to the heart and resulting bradycardia. The results of the above is a hypokinetic circulation of blood and blood pooling in the extremities.
3. Classifications for sporting events:

   Class IA--Upper cervical lesions with triceps non functional against gravity. A person with this disability cannot lift his arms above his head and cannot grip with his hands.

Class IB--Lower cervicals with good triceps and strong finger flexors or extensors of functional value. A person with this disability can lift his arms above his head but not against resistance and can grip with some strength.

Class IC--Lower cervicals with good triceps and strong finger flexors and extensors. No onterossei or lumbricals of functional value. A person with this disability can lift his arms above his head against resistance and can grip firmly.

Class II--Below Th1-Th5 inclusive. No balance when sitting. This person has weak abdominal and back muscles but has full use of his arms.

Class III--Below Th5-Th10 inclusive. Ability to keep balance when sitting ignoring nonfunctional lower abdominal muscles (cannot act without falling over if slightly pushed).

Class IV--Th11-Th13 inclusive. A person with this disability is affected from the hips down and in some cases will have some balance difficulties.

Class V--Below L3-S5. This person is usually affected from the hip down and quite often only one leg.

Class VI--This class for swimming competitions only. Below L5. This person is able to kick with some effect.

4. Adjusted R^2: R^2 adjusted for both sample size and number of subjects in sample, i.e.,

$$\text{adj } R^2 = 1 - K^2 \frac{(N - 1)}{(N - m)}$$

where: N = size of the sample

m = number of variables on the problem

(N-m) = degree of freedom

$K = (1 - R^2)$

5. Adjusted Press Prediction: Predicted value for the case after removing the effects of that case removed from the regression coefficients.
6. Deleted Press Residual: The residual error for each case from predicting that case by means of the Adjusted Press Prediction.

Abbreviations

1. MVO2L: Maximum oxygen uptake in Liters/minute
2. MVO2ml: Maximum oxygen uptake ml/kg.min.
3. VO2L: The rate of oxygen uptake L/min.
4. VO2ml: The rate of oxygen uptake ml/kg·min.
5. VCO2L: The rate of carbon dioxide expired L/min.
6. VCO2ml: The rate of carbon dioxide expired ml/kg·min.
7. Sub-RQ: Submaximum Respiratory Quotient
8. Vent.: Ventilation rate L/min.
9. HR: heart rate beats/min.
10. WL: Workload Kpm/min.

CHAPTER II

REVIEW OF LITERATURE

Description of the Population

Lesion of the spinal cord results in the loss of nervous supply to the segments of the body below the level of the lesion. Atrophy of the muscles normally served by the respective nerves, is a common observation. Body weights in paraplegics and quadraplegics have been reported to average about 80% of predicted values from height tables (Hjeltnes, 1977).

The loss of innervation is not restricted to the muscle tissue. A lesion at any level results in the loss of central control of sympathetic outflow to parts of the body below that level. A lesion at the level of the splanchnic plexus, thoracic 6-7 vertebrae, results in the greater part of the body and blood vessels being deprived of the normal sympathetic vasomotor control (Wolf & Magora, 1976).

The loss of the splanchnic outflow results in reduced capacities of the circulatory system to adapt to stress, i.e., changes in body position and/or exercise (Knutsson et al., 1973; Wolf & Magora, 1976). Erect position causes an accumulation of blood in the lower extremities. Exercise of the upper limbs causes a vasodilation in these muscles, thus blood pools in the extremities. Redistribution of blood from the core to the working muscles, via a vasoconstriction in the abdominal organs, is absent or reduced. The decrease in peripheral resistance accompanied by the inability to redistribute blood, results in a reduced return to the heart. Increases in cardiac output are limited and a fall in blood pressure occurs.

Wolf and Magora (1976), investigated the effects of position change in relation to systolic blood pressure. Various levels of spinal lesions were observed. Eighteen men, ages 18-62 (3 quadraplegics, 5 high thoracic paraplegics, 7 low thoracic, and 3 lumbar paraplegics) were investigated. Systolic blood pressure decreased markedly in cervical and high thoracic patients in the erect position. Further decreases were seen during effort. Low thoracic and lumbar groups showed little change in systolic blood pressure as a result of change in body position. There was marked decrease in systolic blood pressure during effort.

With increased time following the spinal lesion, an increased tolerance to changes in body position occurs. A change in renin release has been suggested to explain the increased tolerance to vertical position (Knutsson et al., 1973; Guttman, 1946; Guttman, 1954; Jonason, 1947), since increased renin release has been reported after a series of repeated changes in body position (Johnson et al., 1969). The increased tolerance to vertical position could not be accounted for by increased blood volume, as these are reported to be low in chronic paraplegia (Knutsson et al., 1973).

The problem of circulatory adjustment to stress is further complicated with high spinal lesions, those above the thoracic 6-7 vertebrae. High spinal lesions deprive the upper and lower body of sympathetic outflow. The sympathetic acceleratory influence to the heart is reduced or abolished (Knutsson et al., 1973; Freyschuss & Knutsson, 1969: Freyschuss, 1970; Wolf & Magora, 1976).

Knutsson et al. (1973), reported subjects with lesions between cervical vertebrae 5 (C5) to thoracic vertebrae 3 (Th3) incomplete and complete at

Th4, to have maximum heart rates varying between 100 and 130 beats/minute.

Wolf and Magora (1976), found in two patients with cervical lesions, the heart rate did not increase over 120 beats/minute. Only slight increases in heart rate were observed in patients with high thoracic lesions. Normal physiological responses of heart rate were found in both low thoracic and lumbar groups.

Freyschuss and Knutsson (1969), observed in patients with complete cervical cord transections that heart rate increases normally seen during voluntary contraction in a non-paretic muscle group, were completely abolished by atropin block. The increased heart rate response to effort to contract remained intact in healthy normals after atropin block (Freyschuss, 1970). Increased heart rate response must originate from the supraspinal centers and be elicited by an inhibition of vagal outflow to the heart, (Knutsson et al., 1973). He concluded that heart rate regulation in complete cervical cord transections is attained by varying the vagal tone.

Wicks et al. (1977), examined 72 athletes at the 1976 Olympiad for the physically disabled. The average maximum heart rates for paraplegics and quadraplegics with spinal cord lesions were: 182 $\pm$ 13 beats/minute and 132 $\pm$ 17 beats/minute, respectively. Paraplegics, victims of polio, did not differ from those with spinal injuries. However, quadraplegics, polio victims, had heart rates averaging 167 $\pm$ 27 beats/minute as compared to the 132 $\pm$ 17, found with paraplegics with spinal cord lesions.

Nilsson et al. (1975), found in two subjects with high lesions (C6-7 and C7-Th1) had maximum heart rates of 165 and 150, respectively. Similar results were reported for one subject, age 24, with a spinal lesion at Th2, whose maximum heart rate was reported to be only 160. Eight other subjects (low thoracic) had normal maximum heart rate values reported.

Corbett et al. (1971), reported that heart rate response of quadraplegics to head-up tilting was greater than that which could be explained by variation of vagal tone. The beta-receptor reflex acting through the isolated spinal cord has been suggested as an explanation for this and the well-known hyperflexia in patients with high spinal cord transections (Guttman, 1947; Pollock et al., 1951; Cunningham et al., 1953; Whitteridge, 1954; Kurnick, 1956; Cole et al., 1967).

The mode of increasing cardiac output during exercise is mainly via increased heart rate. Stroke volume has been found to increase only slightly. Hjeltnes (1977), investigated the cardiovascular adaptations to work of nine paraplegics, Th6-Th12 lesions. Increases in cardiac output ranged from 54-105% with a mean of 67%. Stroke volume increases accounted for 6-36% (mean 24%) of the increased cardiac output. At an oxygen uptake of 1 liter/minute, the extrapolated values of stroke volume in paraplegics were 43-66ml. Corresponding values in seven healthy subjects were 59-100ml. In one subject, oxygen uptake increased 62%, cardiac output increased 27%, while stroke volume decreased 12%.

Lower stroke volumes may be accounted for by decreased venous return as a result of hypokinetic circulation. In higher lesions, the reduced sympathetic inotropic effect on the heart muscle, which normally results in greater force of cardiac contraction and lower end systolic volumes, may be a factor.

Few studies have attempted to assess the maximum oxygen uptake capacities of wheelchair subjects. Wicks et al. (1976), assessed maximum oxygen uptake capacities of 72 athletes. The findings were categorized on the basis of International Classifications, i.e., IA, IB, II, III, IV. The reported maximum capacities are: 15.9, 15.8, 24.0, 31.1, 39.0 ml/kg·min., respectively.

Cameron et al. (1976), examined the aerobic capacities of 42 athletes. Categorization was made on the basis of the type of sport participated in. Wheelchair track and swimming athletes had maximum oxygen uptakes in excess of 40 ml/kg•min. Skill athletes had the lowest maximum capacities, 24.4 $\pm$ 6.2 ml/kg.min. Strength athletes had values slightly greater, 25.6 $\pm$ 4.5 ml/kg•min. Non specialization in sport participation made it difficult to identify characteristic types for the above.

Zwiren and Bar-or (1975), compared four groups: normal athletes (NA), normal sedentary (NS), wheelchair bound athletes (WA), and wheelchair bound sedentary (WS). The WS subjects were all with lesions below the Th7 level. Arm work was performed with no significant difference found between NA and WA (MVO2ml). Significant differences were reported when maximum oxygen uptake was expressed as MVO2L. The differences in lower body mass, between the two groups probably is an important factor in the interpretations of these results. The author suggested that WS and NS were different in terms of maximum oxygen uptake, even though a significant difference was not found.

Nilsson et al. (1975), examined the aerobic capacities of 12 rehabilitated paraplegic subjects and the effects of training on their aerobic capacities. Two subjects with cervical lesions had maximum oxygen uptakes averaging 16.8 ml/kg•min. (pre-training). The remaining subjects with thoracic lesions, pre-training values averaged about 20.3 ml/kg•min. The subjects varied considerably in age and habitual physical activity levels. Only one of the subjects with a cervical lesion participated in a trainig program. His maximum oxygen uptake increased 3.7 ml/kg•min. Physical training increased in the mean MVO2ml, for the group with thoracic lesions, to 26.9 ml/kg.min.

Hjeltnes (1977), examined nine paraplegic subjects, eight with low thoracic lesions (Th6–Th12) and one with a Th2 lesion. Subjects varied in age from 17-46 years, mean 26.8. Maximum oxygen uptake ranged from 1.1 l/min. to 1.7 l/min. (20.8 ml/kg•min. to 36.6 ml/kg•min., mean 27.4 ml/kg•min.)

Several investigators have reported the efficiency with which the subjects perform the work. Brubaker et al. (1979), reported mechanical efficiencies at three different work loads: .25, .33, and .50 watts/kg of body weight. The mechanical efficiencies reported are: 9.33, 10.55, and 11.49 per cent, respectively. Mechanical efficiencies at two different speeds were also investigated, corresponding to workloads of 2.0 and 3.0 kpm/min. Mechanic efficiencies were reported to be 11.29% and 9.62%, respectively.

Barr and Glaser (1977), reported mechanical efficiency to decrease with increased workload. The value decreased from 9% to 6% for workloads varying from 50 to 150 kpm/min. No mention was made of how load increases were achieved, i.e., by increases in speed or increases in resistance.

Glaser, Young, and Suryaprasad (1977) investigated the mechanical efficiency of various methods of striding, i.e., normal-synchronous versus asynchronous technique. Mechanical efficiencies of 4.7% and 7.4%, respectively, were reported.

Marincek and Vojko (1978), using arm cycloergometry, reported mechanical efficiencies of five subjects to vary from 16.1 to 20.7%. These results agree with the findings of Bevergard et al. (1966), who reported mechanical efficiencies of 18 and 23% for arm and leg work, respectively.

Nilsson et al. (1975), examined the effects of training on mechanical efficiency of 12 paraplegics. Arm cycloergometry was employed. Pretrained values averaged: 16.0 ± 1.9% at submaximal work of 300-370 kpm/min. and 18.3 ± 2.9% at maximum effort. These values were increased to 18.3 ± 2.9% and 21.5 ± 2.9% respectively.

The variation in magnitude of the reported mechanical efficiencies for the various studies may result from the use of different methods of calculation. In most cases the method was not reported making interpretations difficult.

Prediction of Maximum Oxygen Uptake

Prediction of maximum oxygen uptake has been and continues to be the concern of many exercise physiologists. Several methods have been developed. Researchers have reported varying degrees of success with each. Table 1 lists the majority of the methods reported to date, and the accuracy of prediction using the various methods.

It is not the purpose of this chapter to do an in-depth review of each method and/or the various studies which have looked at these. The reader is referred to Astrand and Rodahl (1970) and Davies (1968) for a more in-depth review of the prediction of maximum oxygen uptake by means of the extrapolation methods. The limitations of each have been well documented in these and other exercise physiology texts. An overview of the more popular methods will be made here with a more detailed look at prediction of maximum oxygen uptake via multiple regression equations.

Astrand and Rhyming (1954), initiated one method which utilized heart rate and the measurement of or estimated oxygen uptake at a submaximum workload, to predict maximum oxygen uptake values. A straight line is fitted between a "common" heart rate of 61 beats/min. (at zero oxygen consumption) and the measured heart rate at the oxygen consumption for a particular sub-

Table 1. A Summary of Investigations into the Accuracy of Predicting Maximum Oxygen Uptake Utilizing the Methods Indicated

Study*	N	Sample distribution	Particulars	Error
<u>Astrand & Rhyming (1954) method</u>				
Astrand & Rhyming (1954)		males	bike ergometry @ 900 kpm	10.4%***
		males	bike ergometry @ 1200 kpm	6.7%***
		females	bike ergometry @ 600 kpm	14.4%***
		females	bike ergometry @ 900 kpm	9.4%***
Hermiston & Faulkner (1971)	28	normals	MVO2 determined by treadmill	
			submaximal HR less than 140 (N=5)	
			submaximal HR greater than 140 (N=23)	
			prediction via nomogram	15% $\pm$ 11
Davies (1968)	80	normals, ages 20-50	bike ergometry	
			submaximum HR 120-140	18% $\pm$ 12
			submaximum HR 140+	12% $\pm$ 8
			prediction via nomogram	
Glassford et al. (1965)	24	physically active males	prediction via nomogram compared to:	
			MVO2 observed bike ergometry	9% $\pm$ 9
			MOV2 observed treadmill	0% $\pm$ 20

*Study--Investigations which have tested the accuracy of the indicated methods

Errors: All errors reported as mean % error of prediction $\pm$ standard deviations

**Absolute percent variation $\pm$ SD, i.e., $\frac{\text{sum of residual errors}}{\text{observed MVO2}} \times 100\% \div N$

***Coefficient of variation, i.e., $\frac{\text{standard error of estimate}}{\text{mean observed MVO2}} \times 100\%$

Table 1, continued

Study*	N	Sample distribution	Particulars	Error
Rowell et al. (1964)	10	nonathletes	pre-training	27% ± 7
	10	nonathletes	post-training	14% ± 7
	12	athletes		6% ± 4
			prediction via nomogram	
Joseph et al. (1973)	20	males, ages 20-30	MVO2 via bike ergometry prediction via nomogram WL for all subjects 750 kpm	5% ± 9
DeVries & Klafs (1965)	16	males, ages 20-26	MVO2 via bike ergometry prediction via nomogram WL all subjects 900 kpm	9.3%***
Verma (1977)	45		MVO2 determined via bike ergometry prediction via nomogram	11.62 ± .72**
<u>Maritz-Wyndham (1967) method</u>				
Davies (1968)	80	normals, ages 20-50	prediction via extrapolation of the line produced from two submaximum work rates (sub HR between 130-170) bike ergometry	12% ± 9
Rowell et al. (1964)	10	endurance athletes ages 18-24	treadmill exercise extrapolation to MAX HR of 195	15% ± 8
	7	sedentary males ages 20-30	pre-training	23% ± 7
			post-training	18% ± 8

Table 1, continued

Study*	N	Sample distribution	Particulars	Error
Verma (1977)	45	moderately active	bike ergometry WL: 600, 750, and 900 best-fit line fitted to three points; extrapolated to 180 Max HR	14% ± 1**
<u>Margaria et al. (1965) method</u>				
Margaria et al. (1965)		males and females ages 9–47	step test (30–40) cm bench) prediction via nomogram	1% ± 6
Davies (1968)	80	normals, ages 20–50	step test prediction via nomogram	10% ± 7
<u>Issekutz et al. (1962) method</u>				
Issekutz et al. (1962)	24	males, ages 20–65 females, ages 55–65 all untrained	bike ergometry change in RQ, ie., log RQ vs VO2L produces a straight line	.0% ± 4.86
DeVries & Kalfs (1965)	16	males, ages 20–26	MVO2 determined via bike ergometry	8% ± 18
Joseph et al. (1977)	14	soldiers, ages 20–30	bike ergometry	18% ± 11

Table 1, continued

Study*	N	Sample distribution	Particulars	Error
Shephard (1967)	10	sedentary	progressive step test	0% ± 8.5
<u>Fox (1973) method</u>				
Fox (1973)	87	untrained college males	MVO2L = 6,300 - 19.26 (HR) HR: heart rate response to 150 watts (work rate during bike erg.) linear regression	.01 ± 7.8 9.6%***
<u>Hermiston & Faulkner (1971) method</u>				
Hermiston & Faulkner (1971)	36 36	males, active males, inactive	treadmill multiple regression separate equations for each group prediction accuracy increased over total group prediction equation anthropometric and cardiorespiratory variables	2% + 8
<u>Mastropaolo (1970) method</u>				
Mastropaolo (1970)	13	middle-aged males	bike ergometry multiple regression anthropometric and cardiorespiratory variables	5% + 3 6.6%***

maximum workload. Maximum oxygen uptake is obtained from the extrapolation of the straight line to a population maximum heart rate (195 beats/min). Nomograms have been developed for both step-tests and bike ergometry.

Maritz et al. (1962) utilized four submaximal rates of work. VO2L and HR for each workload were plotted and a straight line fitted to four pairs of values. Extrapolation was made to a maximum heart rate of 180 beats/min. Work was performed on a bike ergometer.

Margaria et al. (1956), employed two rates of work (stepping up and down, on and off a bench) which produced a heart rate between 100-150 beats/min. Adjustments were incorporated for the very young and very old, i.e., three maximum heart rate lines are given in the nomogram to take into account the effects of age on maximum heart rate.

All three of these extrapolation methods rely on assumptions:

1. A linear relationship exists between heart rate and oxygen uptake.
2. Inter-individual variations of heart rate about the population mean is sufficiently small for the population mean to be used as the maximum heart rate for all subjects.
3. The mechanical efficiency for all subjects is about 23% (when oxygen uptake for submaximum work is assumed).

The validity of 1 and 2 has been questioned by many investigators, as noted in Chapter I. The coefficient of variation in mechanical efficiency of 4-5% reported by Shephard (1977), is suggested to be 6% by Astrand and Rodahl (1970).

The accuracy of prediction is dependent on a number of factors which reflect the validity of the above assumptions. Fitness levels are of prime concern. Davies (1968), notes that only in subjects with a high observed maximum oxygen uptake (where the decline in maximum heart rate tends to compensate for the asymptotic nature of heart rate), does the procedure of extrapolation of the line HR versus VO2 to a mean population pulse of 190, produce realistic results. Underestimation of maximum oxygen uptake is the trend for more sedentary subjects. Rowell et al. (1964), reported similar conclusions.

In the case of younger subjects, any method which employs a maximum heart rate of 170 or 180 will underestimate the true maximum oxygen uptake. Age adjustments have been made in some cases (Astrand & Rodahl, 1970; Margaria, 1965).

Prediction is also dependent on many environmental factors. Ambient temperature, humidity, and the partial pressure of oxygen (elevation) can all influence the physiological stress placed on the body and in so doing, influence the submaximal response (Astrand & Rodahl, 1970).

Rowell et al. (1964), listed several factors that will cause heart rate to vary independent of oxygen uptake. These include physical conditioning, elapsed time after previous meal, total circulating hemoglobin, the degree of hydration of the subject, and hydrostatically induced changes resulting from prolonged erect position.

Issekutz et al. (1962), investigated an alternative method to extrapolation, i.e., the change in the respiratory quotient. They reported the value: working RQ - .75, increased logarithmically with the workload and maximum oxygen uptake was reached when this value became equal to .40. Varying degrees of success have been reported using this method. Table 1 may be referred to for a summary of the various results.

The variability in success found with the preceding methods, has led investigators to the use of more variables for the prediction of maximum oxygen uptake. Multiple regression equations have been developed by several authors (Bell & Hinson, 1974; Bonen & Babineau, 1977; Fall et al., 1966; Fox, 1973; Hermiston & Faulkner, 1971; Jessup et al., 1974; Jette et al., 1976; Mastropaolo, 1970).

Mastropaolo (1970), obtained a simple regression by stepwise multiple regression analysis. Thirteen middle aged men were exercised to maximum oxygen uptake. Submaximal and maximal heart rate, systolic blood pressure, expired volumes, expired carbon dioxide and oxygen were determined. In this study submaximum RQ and maximum oxygen uptake were found to be highly correlated, r=.89 and a standard error of estimate of .175. The addition of work rate raised the multiple correlation to .92 and decreased the standard error of estimate to .156 L/min. The multiple regression equation developed from these two submaximum variables is as follows: MVO2L = 11.158 - 0.007(WL) - 4.517(RQ). The reported best prediction equation was: MVO2L = 14.703 - 4.909(RQ) - 0.008(WL) - 0.004(blood pressure) + 0.018 (Vent) - 16.083(VO2L), obtained at 600 kpm/min. The multiple regression correlation coefficient was reported to be .93 with a standard error of estimate of .172 L/min. Deviations from the true values ranged from -8% to +11%, mean of +.3%, absolute mean of 5.4% with a standard deviation of 3%. Of the 13 subjects, 3 trained for 12 weeks and were tested again. Pre-training values resulted in an estimate between -5% and +4% of true MVO2L, while post training prediction underestimated MVO2L by 8%.

It is noted that Mastropaolo reported the second multiple regression equation as the "Best." The standard error of estimate was greater and the adjusted R^2 would be considerably less than that reported for the equation using only RQ and WL. When small sample sizes are used, it is important to report the adjusted R^2 value. Small sample sizes tend to inflate the multiple correlation coefficient, as does the use of a large number of variables.

Hermiston and Faulkner (1971), looked at 25 anthropometric and cardiorespiratory submaximal variables. Data were collected on 60 men. The overall group was divided on the basis of physical activity levels into two interlocking groups, a physically active group (N=36) and a physically inactive group (N=36). Data on 12 border-line subjects were included in both groups. Prediction equations were developed for: total group data; as well as for each group. The regression equation for the total group did not provide an accurate prediction of maximum oxygen uptake, R=.54. Regression equations for each of the sub-groupings raised the R to .90 in each case. The percent error for prediction using either equation was reported as $2 \pm 8\%$.

Fox (1973), found a multiple correlation of .78, utilizing body weight, height, and submaximal heart rate at a workload of 150 watts. This did not significantly predict MVO2ml better than the use of heart rate response alone. The prediction equation (utilizing only the heart rate response during the fifth minute of exercise at a work rate of 150 watts) is as follows: MVO2ml = 6300 - 19.26(HR), standard error of estimate: 246 ml/min. (7.8%). Prediction of MVO2ml made on a group of subjects taken from the literature, was not significantly different from measured values before and after training, or with age variation ($\bar{X} \pm$ SD : 3.13 $\pm$ .43 L/min., measured: 3.1 $\pm$ .36 L/min., predicted [r=.83]). This method does not rely on the premise that HR increases linearly with oxygen consumption and workload over the entire range of workloads to maximum effort.

Jette et al. (1976), investigated the possibility that maximum oxygen uptake could be predicted from independent variables measured during the administration of the Canadian Home Fitness Test. Fifty-nine subjects, ages 15–74 years, underwent the fitness test and progressive exercise treadmill test for direct determination of volitional maximum oxygen uptake. The following multiple regression equation was found to produce a multiple R of .905: MVO2ml = 42.5 + 16.6(VO2L) – .12(Wt) – .12(post exercise heart rate) – .24(AG). VO2L as used in this equation, represents the average oxygen cost for the last completed exercise stage of a steptest (table values).

Bonen et al. (1979), investigated the use of multiple regression equations for the prediction of maximum oxygen uptake in boys, ages 7–15. Data were collected on 100 subjects. Prediction equations for MVO2L were obtained from subjects height, VO2L, and HR observed during the third minute of a treadmill walk, R = .95, CV = $\pm$ 9.7%. When just subject height, weight, and age were used, similar results were obtained. MVO2ml was also predicted from age, HR, VCO2L, and VCO2ml. Slightly better accuracy was the result, coefficient of variation equal to 8.4%. Cross-validation on 39 boys (trained) resulted in a prediction error of about 1–2% $\pm$ 9%. The use of just age, height, and weight was found to underestimate both MVO2L and MVO2ml.

Jessup et al. (1974), incorporated the results of a 12-minute run, Astrand-Rhyming test, age, height, weight, diastolic blood pressure, and leg length to predict maximum oxygen uptake. Forty male volunteers were studied. The best prediction equation was: MVO2L = 1.46 + 0.005(AG) – 0.118(height) + 0.014(WT). + 0.007(diastolic blood pressure) + 0.099(leg length) + 0.232(12-minute run) + Astrand(0.345). The multiple correlation coefficient was reported as: 0.814 with a standard error of estimate equal to 0.188 l/min.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Twenty male subjects volunteered to take part in the study. The group consisted of 5 quadraplegics and 15 paraplegics. Ages ranged from 17 to 53. All subjects were stabilized and had spent a minimum of six months in their wheelchairs. Two subjects were eventually rejected from the study for two reasons: 1) premature termination of the work session, i.e., RQ .86; 2) ECG was lost during the work session.

Data Collection

Testing took place in the Buchanan Fitness and Research Center, University of British Columbia. Heart rate was monitored by direct ECG utilizing an Avionic 4000 cardiograph with oscilloscope and ST depression computer and display. Heart rate responses were measured during the final 15 seconds of each minute of both rest and exercise.

Expired gases were continuously sampled and analyzed by a Bechman Metabolic Measurement Cart (BMMC) interfaced into a Hewlett Packard 3052A Data Acquisition system for 15 second determinations of respiratory gas exchange variables.

Each subject reported to the lab on the day of testing. Body weights were measured in a variety of ways, depending on the subject. Lighter subjects (unable to stand) were held by one of the testers and the total of the two individuals was measured. The tester's weight was then subtracted from the total. With larger individuals, the weight scale was placed on a table. Subjects, with the aid of the testers, lifted themselves out of their chairs onto the scale. Finally, subjects with very low spinal lesions or other incapacitation which left them able to stand (with assistance), were weighed standing on the scales. All body weights were assessed with subjects wearing pants or sweat pants less shoes and shirts.

Maximum breathing capacities were assessed prior to the metabolic measures. A Collins 13.5 liter respirometer was used for this measurement. Two 12-second trials were permitted. The first usually serving as a practice trial and the second as the recorded measure. In all cases, the best score was recorded.

During a progressive continuous work session, cardiorespiratory data were collected. The protocol for load increases varied between quadraplegics and paraplegics. Initial load increases were achieved by increases in resistance. Increases of 1 kg were applied each minute until values of 4.5kg and 7.5kg were achieved for quadraplegics and paraplegics, respectively. Subsequent load increases were arrived at by increased speed. Initial speed was set at 20 rpm of the wheelchair wheels and increased 5 rpm/min. until the subject could no longer match the required work rate or the subject terminated the work bout. Table 2 illustrates the work protocol for the two groups.

For each workload the last two of the four respiratory gas exchange determinations were averaged, i.e., the last 30 seconds at each workload. Heart rate was recorded during the last 15 seconds at each workload. Maximum oxygen uptake was reported as the highest of the 30 second averaged values. Work was performed on a wheelchair ergometer. A detailed

Table 2. Protocols for continuous increasing workloads

Time	Paraplegics resistance	speed	Quadraplegics resistance	speed
0-1	internal	20 rpm	internal	20 rpm
1-2	internal	20 rpm	internal	20 rpm
2-3	3.5 kg	20 rpm	3.5 kg	20 rpm
3-4	4.5 kg	20 rpm	4.5 kg	20 rpm
4-5	5.5 kg	20 rpm	4.5 kg	25 rpm
5-6	6.5 kg	20 rpm	4.5 kg	30 rpm
6-7	7.5 kg	20 rpm	4.5 kg	35 rpm
7-8	7.5 kg	25 rpm	4.5 kg	40 rpm
8-9	7.5 kg	30 rpm	4.5 kg	45 rpm
9-10	7.5 kg	35 rpm	4.5 kg	50 rpm
10-11	7.5 kg	40 rpm		
11-12	7.5 kg	45 rpm		
12-13	7.5 kg	50 rpm		
13-14	7.5 kg	55 rpm		
14-15	7.5 kg	60 rpm		

description of this ergometer appears in Appendix A.

Data Analysis

Difficulty in equating workloads to functional and structural characteristic of the combined group of paraplegics and quadraplegics, necessitated the division of the total group. Two sub-groups were produced para-plegics (N=13) and quadraplegics (N=5).

Three lines of data were selected for each paraplegic. Each line represented the cardiorespiratory responses to a workload, where the heart rate value was found to be between 65% and 85% of maximum heart rate (maximum heart rate = 220 - age). In cases where less than three values of sub-maximum HR were found within this range, the closest HR value(s) outside the limits, were added. Where more than three submaximum HR values fell within the limits, the WL and corresponding cardiorespiratory values were deleted, using the following criteria:

1. where two HR responses were found to be very close in numerical values, the lowest was deleted,
2. where the HR response was very close to the lower limit, it was deleted.

Appendix B lists complete data sets for all subjects. The three lines of data selected from each subject's data set, are indicated.

Each of the three lines were assigned to one of three groupings:

LHR: data line corresponding to the lowest HR

MHR: data line corresponding to the middle HR

HHR: data line corresponding to the highest HR

Multiple regression analysis was carried out on each of the LHR, MHR, and HHR groups. The UBC Computing Center's:BMD P:2R (stepwise multiple regression) and BMD P:9R ("Best" subset multiple regression) programs were employed for the analysis.

The data analysis for the quadraplegics was arranged differently. Prediction of maximum HR was not possible at the time of the present study and no research has been conducted to determine the range between resting heart rate and maximum heart rate where prediction of maximum oxygen uptake will be most accurate. Therefore, one WL and corresponding cardiorespiratory responses was selected from each subject's data set. This line of data represented the fourth minute of work for each subject. Stepwise multiple regression analysis was performed on this data, UBC Computing Center's P:2R.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Twenty male subjects were tested. Two were deleted from the study for reasons noted in Chapter III. The final group of 18 physically disabled individuals were divided into two groups: paraplegics (N=13) and quadraplegics (N=5). Subjects structural characteristics appear in Table 3. Individual physiological responses to the progressive continuous workload protocol, appears in Appendix B.

Multiple correlation analysis was performed on the paraplegics' physiological responses to each of three work intensities, (LHR, MHR, and HHR). Respective mean heart rates were approximately: 70%, 75%, and 80% of the predicted maximum heart rate for the group, i.e., 220 - the mean age of the group. Table 4 lists the mean values for the workloads and physiological responses to each work intensity.

Correlation coefficients between the 11 predictors and the criterion at the three work intensities, are reported in Table 5. At the lowest work intensity, six variables were found to be significantly correlated to the criterion at the .05 level of significance. Only two variables, WL and VO2L correlated significantly to the criterion, at the .01 level. The MHR intensity produced five variables correlated to MVO2L (significant at the .05 level). Six variables were significant (.05 level) for the HHR intensity. Three and four variables were significantly related to the criterion

Table 3. Subject Characteristics

Subjects	Age (yrs)	Weight (kg)	Type of Injury
01	38	79.4	lesion Th10
02	38	78.0	lesion Th5-6
03	53	95.5	lesion L4-5
04	38	87.5	lesion C6
05	18	56.0	
06	22	54.0	lesion C6-7
07	29	70.6	lesion Th12-L1
08	25	61.7	lesion C7
09	31	69.0	lesion L1
10	26	70.0	Polio
11	48	91.8	lesion Th5
12	22	62.1	lesion Th4-5
13	52	65.0	lesion Th10
14	37	66.9	lesion C5
15	33	84.0	
16	21	64.0	
17	21	60.0	lesion C6-7
18	35	53.0	Polio
Paraplegics			
Mean	34	72.0	
Std Dev	11.5	13.0	
Quadraplegics			
Mean	28.6	66.0	
Std Dev	8.3	12.9	

Table 4. Means and Standard Deviation of Variable Corresponding to LHR, MHR, and HHR

	LHR		MHR		HHR	
Variables	Means	Std Dev	Means	Std Dev	Means	Std Dev
WL	421	102	451	122	529	123
HR	131	12	139	12	149	13
VO2L	1.25	.303	1.37	.357	1.60	.399
VO2ml	18.3	5.80	19.0	5.36	22.6	8.22
VCO2L	1.12	.318	1.31	.416	1.60	.484
VCO2ml	15.7	4.98	18.2	6.34	22.5	6.78
RQ	.89	.09	.94	.11	1.00	.11
Vent L	29.8	7.59	33.4	10.1	43.4	11.8

Table 5. Summary of Correlation coefficients between predictors and criterion MVO2 L/min

Work Intensity	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L
LHR	.013	.530	-.513	.816	.600	.873	.718	.714	.586	.065	.535
MHR	.013	.530	-.513	.784	.667	.763	.767	.588	.552	-.051	.507
HHR	.013	.530	-.513	.834	.525	.873	.718	.714	.586	-.066	.651
	Correlation coefficient required for significance: 0.553 @ .05; 0.684 @ .01										
Quadraplegics	.775	-.443	.665	-.515	.493	.774	-.402	.843	-.033	.499	.852
	Correlation coefficient required for significance: 0.805 @ .10; .878 @ .05										

(.01 level) for the MHR and the HHR intensities, respectively. Complete correlation matrices appear in Appendix C.

Multiple regression analysis revealed significant adjusted multiple correlation coefficients (adj R^2), between the five best predictors and the criterion. This was observed at all three work intensities. A summary of the results of the multiple regression analysis is provided in Table 6. At the two higher work intensities an increase in the adj R^2 and a reduced standard error of estimate were observed. Significance of these differences was not determined. Figures 1-3 graphically illustrate the prediction accuracy of the multiple regression equations developed for the three work intensities.

A comparison which may better indicate the accuracy of the prediction of MVO2L for subjects outside the experimental group, is illustrated in Figures 4-6 (Observed vs Adjusted Press Predicted MVO2L). Prediction is made, in turn for each subject with the effects of his data removed from the regression coefficients. Over all work intensities, the deleted press residual error was found to be greater than the residual error resulting from the unadjusted multiple regression equations. The greatest scattering of plots about the line of unity, was observed at the LHR intensity. Both the MHR and HHR equations produced much less scattering and did not appear to differ from each other. Table 7 summarizes the residual errors for each equation (page 47).

The use of the UBC Computing Service's P:2R program for stepwise multiple regression analysis, revealed significant limitations of the stepping process. The stepping procedure does not always select the best combination of variables. Since all other steps are affected by the preceding steps and corresponding variables entered, certain variable combinations

Table 6. Summary of multiple regression analysis of paraplegic data

Work Intensity	Variables	Coefficients	Contribution to R_i^2	R^2(adj)	Std Error of est.	Sign.
HHR	Wt	0.0261173	0.323542	0.9094	0.1195	0.0002
	MBC	0.0035206	0.135327			
	AG	-0.0533642	0.325075			
	HR	-0.0340337	0.150292			
	VCO2ml	0.0428753	0.285904			
	Intercept	5.56273				
MHR	AG	-0.0264823	0.083831	0.9218	0.1101	0.0001
	WL	-0.0015175	0.021833			
	HR	-0.0080279	0.015104			
	VCO2L	1.69754	0.202779			
	RQ	-3.42073	0.311303			
	Intercept	5.84850				
LHR	Wt	0.023374	0.415916	0.8761	0.1397	0.0007
	AG	-0.0263043	0.202233			
	HR	-0.0116148	0.031783			
	VCO2ml	0.1083700	0.307697			
	RQ	-2.85780	0.110529			
	Intercept	3.32762				

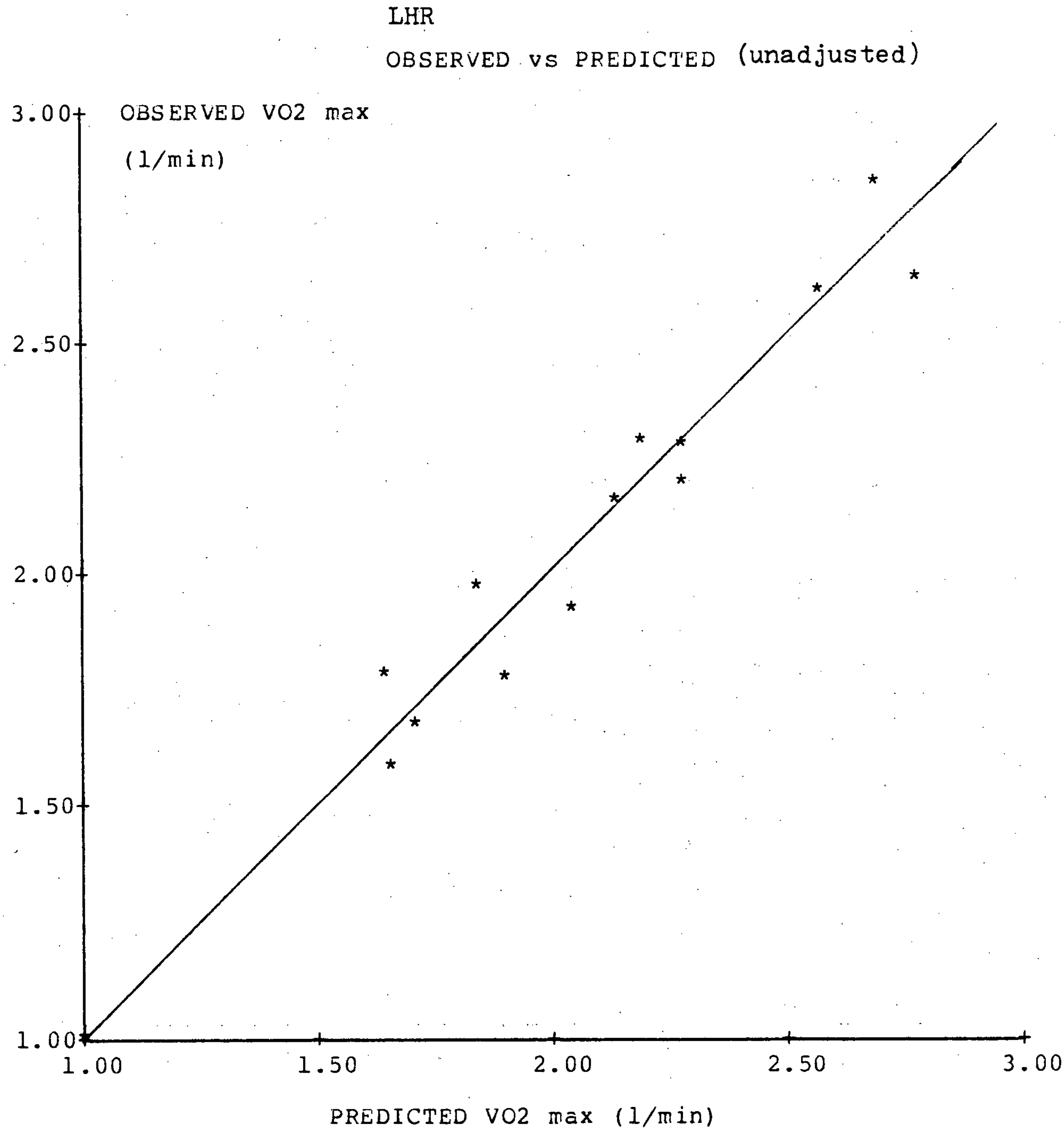

Figure 1. Comparison of MVO2L predicted (unadjusted) vs observed MVO2L for LHR group

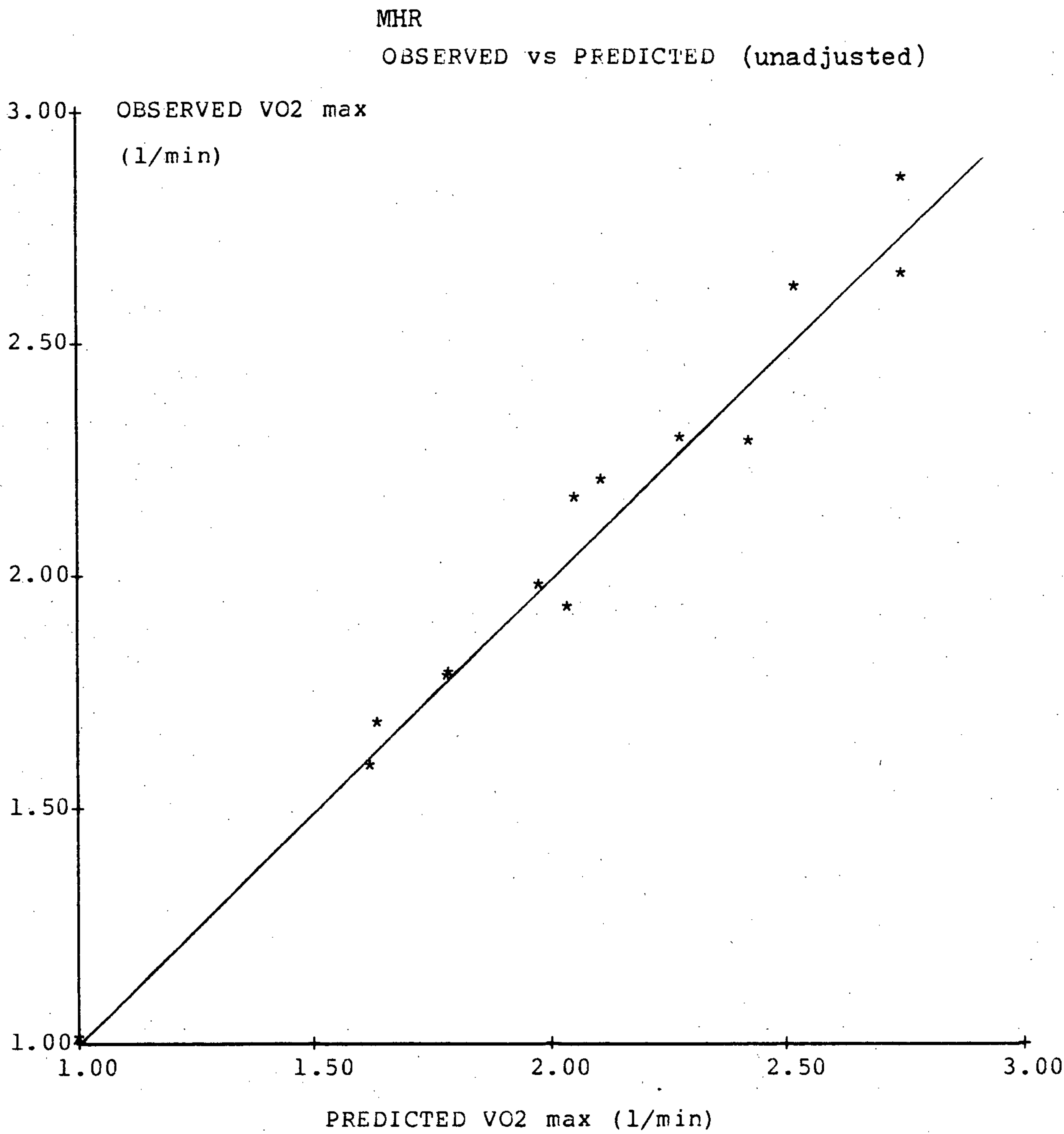

Figure 2. Comparison of MVO2L predicted (unadjusted) vs observed MVO2L for MHR group

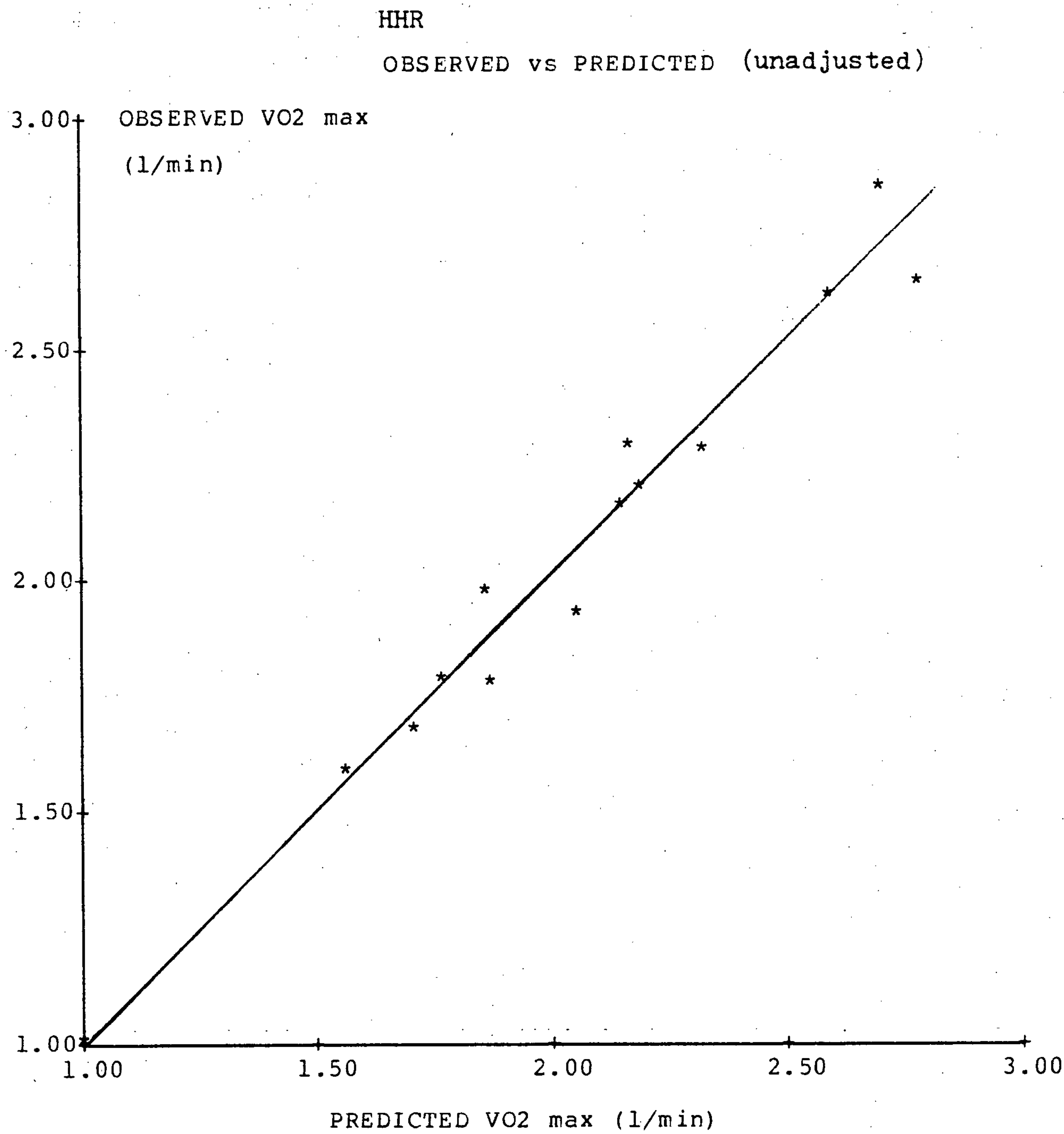

Figure 3. Comprison of MVO2L predicted (unadjusted) vs observed MVO2L for HHR group

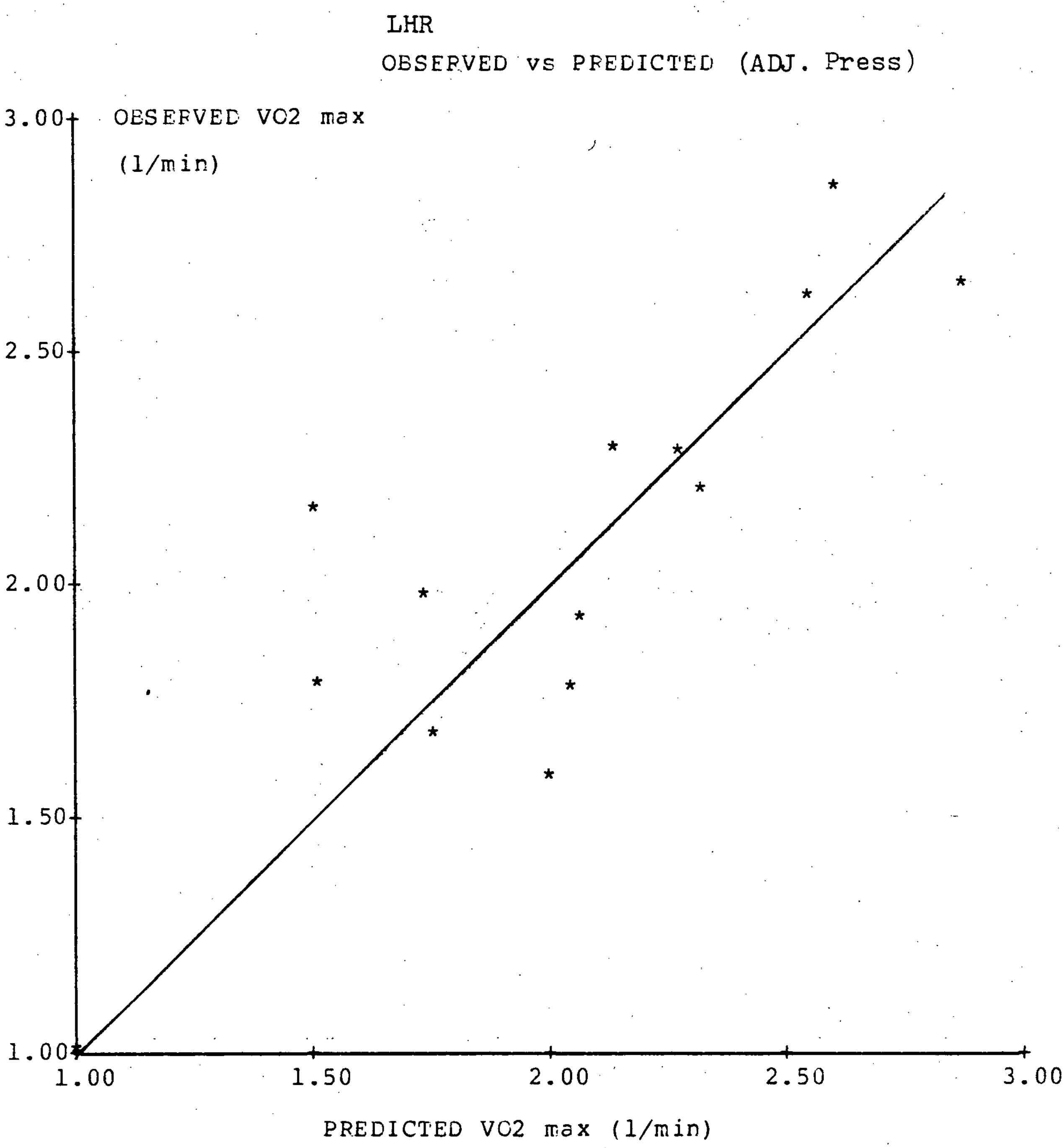

Figure 4. Comparison of MVO2L predicted (adj. press) vs observed MVO2L for LHR group

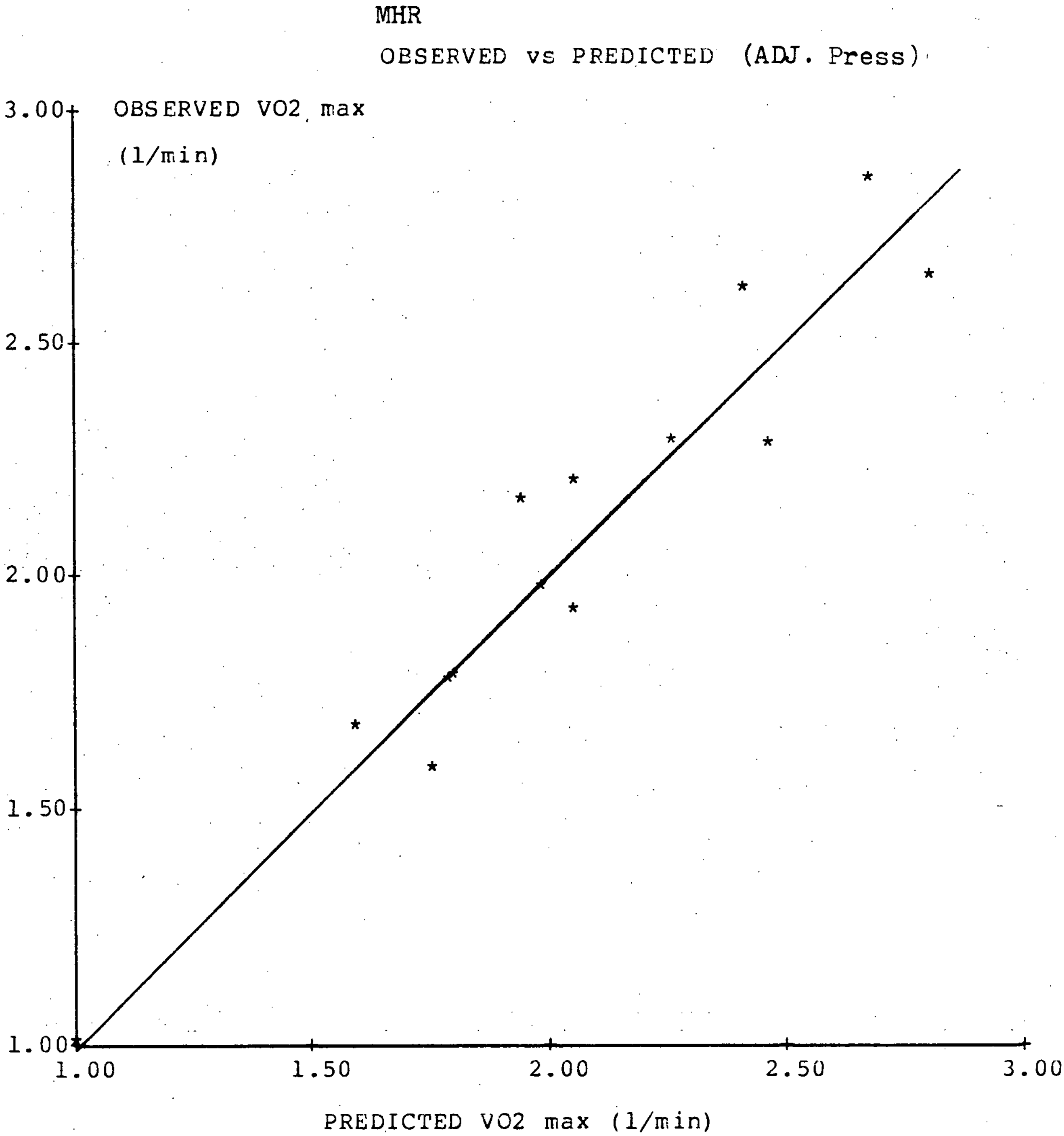

Figure 5. Comparison of MVO2L predicted (adj. press) vs observed MVO2L for MHR group

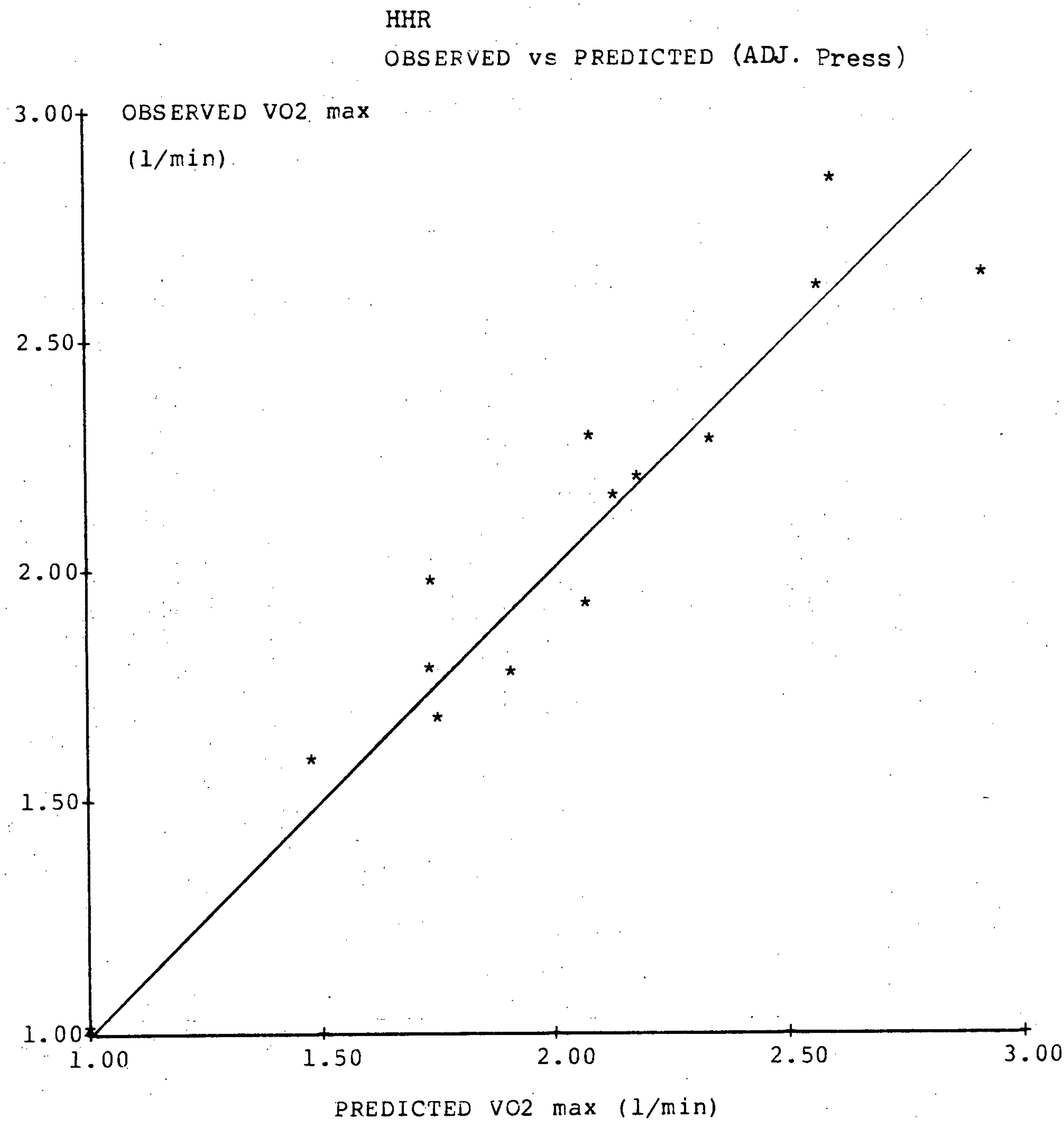

Figure 6. Comparison of MVO2L predicted (adj. press) vs observed MVO2L for HHR group

are not tested. This problem was noted with the LHR equation. The P:2R program's best five predictors included: Wt, AG, WL, HR, and VO2L produced an adj R^2=.8343 as compared to an adj R^2 of .8761 reported in Table 6, a result of the P:9R program.

The P:9R program tests all combinations of the variables in varying numbers. The only problem found with this program was the restrictions of the variables which can be submitted to the program for analysis. Variables which are highly intercorrelated with each other cannot all be submitted. An improper choice to delete one or more variables, may not allow the best subset to be determined. It was found necessary to make several runs with different variable subsets.

Discussion

Analysis of the correlation coefficients, at three work intensities, suggested increased accuracy in prediction may be associated with the higher work intensities, i.e., approximately 70-75% of predicted maximum heart rate. This result is supported by findings which dictate the protocols for submaximal tests currently applied to able bodied subjects (Davies, 1968; Astrand & Rhyming, 1954; Hermiston & Faulker, 1971).

Many variables were found to be significantly correlated to maximum oxygen uptake (MVO2L), however, not all appear in the prediction equation. When two or more variables are intercorrelated, the information contained in each is similar. The higher the intercorrelation coefficients, the greater the similarity. The addition of two or more of these intercorrelated variables to the prediction equation will have little effect on the multiple correlation coefficient and may decrease the adjusted R^2 value. During the stepping procedure of multiple regression analysis, once one of these intercorrelated variables enters the equation the partial correlation coefficients between a remaining variable and the criterion falls, as does the F value to enter.

Variables which are not necessarily significantly correlated to MVO2L and not intercorrelated with other variables, may enter the equation and contribute optimally to the adjusted R^2, i.e., MBC, Wt, AG, and RQ.

It is well documented that the variables VO2L, WL, and HR are significantly intercorrelated when workload is varied over a wide range of submaximal workloads (Astrand & Rodahl, 1970). These relationships provide the basis for the extrapolation methods of predicting MVO2L for able bodied subjects (Astrand & Rhyming, 1954; Maritz et al., 1962; Margaria et al., 1965; Hermiston & Faulkner, 1971; Davies, 1968). Similar relationships have been reported for arm work by both physically disabled and able bodied subjects (Wicks et al., 1973; Glaser et al., 1978a, 1978b). However, a curvilinear relationship between VO2L and workload has also been reported (Wicks et al., 1977; Vokac et al., 1975; Stenberg, 1967; Davies & Sargeant, 1974). This relationship is suggested to be due to the recruitment of trunk muscles to provide stabilization of the shoulders, allowing the subjects to exert greater forces against the wheels of the chair (Vokac et al., 1975; Glaser et al., 1978, 1977; Wicks et al., 1977; Engel & Hilderbrandt, 1973). This produces a fall in mechanical efficiency at higher relative workloads.

Ventilation, VCO2L, and RQ tend to be curvilinearly related to workload, when the workload is varied over a wide range of submaximal workloads (Astrand & Rodahl, 1970; Davis et al., 1976; Wasserman et al., 1973). In theory, lower correlations should be found between these variables and variables which are linearly related to workload. The intercorrelation coefficients observed in this study do not appear to support the above. Very high correlations are observed at all the three work intensities, i.e., VCO2 (L or ml) vs Vent, Vent vs VO2L.

An explanation for these observations relates to the fact that correlation analysis was performed on physiological responses to the same work intensity for each subject. The intercorrelation coefficients reflect how the relationships between the physiological responses to the particular work intensity vary over the 13 subjects. This differs from the determination of how the population's physiological responses are related to each other over a wide range of workloads, i.e., in this study correlation analysis is performed on three small segments of the continuum from rest to maximum exertion. Within the limits of each segment, linearity between variables may be found.

Body weight was found to be nonsignificantly related to MVO2L. This has been reported elsewhere (Jette et al., 1976). The reverse has also occurred (Jessup et al., 1974; Bonen & Belcastro, 1977; Hermiston & Faulkner, 1971), the difference being related to the nature of the population in each study. In children and in young, healthy, lean subjects there is a good correlation between body weight and MVO2L (Astrand, 1952).

The distribution of body weights associated with the subjects of the present study, would suggest a heterogeneous sample and corresponding significant relationship between body weight and MVO2L. This was not found. The relationship appears to be obscured by the variability in the degree of atrophy of lower limb muscles, the varying degrees of obesity, and the age related deterioration of the oxygen transport system, which is not reflected in the dimensions of an individual (Astrand & Rodahl, 1970).

Age was found to be negatively correlated with the criterion. This is a common observation (Astrand & Rodahl, 1970; Hermiston & Faulkner, 1971;

Jette et al., 1976). Where children are involved the trend may be reversed (Bonen & Belcastro, 1977).

Respiratory quotient did not correlate significantly with the criterion at any of the three work intensities. Varying results have been reported, regarding the use of submaximum RQ or the change in RQ in both simple regression (Rowell et al., 1964; Issekutz & Rodahl, 1961; DeVries & Klafs, 1965; Issekutz et al., 1962; Shephard, 1967; Joseph et al., 1972), and multiple regression equations (Hermiston & Faulkner, 1971; Mastropaolo, 1970). Rowell et al. (1964), concluded the use of submaximum RQ was limited since the level of training is a primary determinant in how RQ changes with VO2 during submaximum work. No relationship between RQ and MVO2L was reported.

The use of submaximal RQ in multiple regression equations has lent support to the usefulness of this variable in prediction of maximum oxygen uptake. Mastropaolo (1970), reported a correlation coefficient of .89 between submaximum RQ and MVO2L. Hermiston and Faulkner (1971), did not report a significant correlation between RQ and maximum oxygen uptake. However, in the two equations reported, the change in submaximum RQ alone were found to be important variables in each of the multiple regression equations.

In the present study, the correlation coefficients between submaximum RQ and MVO2L were nonsignificant. Nevertheless, submaximum RQ was incorporated into two of the three multiple regression equations. In each equation, submaximum RQ contributes substantially to the R^2 values.

Maximum RQ values for subjects 02, 16, and 17 were noted to be considerably higher than that normally seen at termination of a maximum work bout. Explanations for this observation may be related to the observed greater proportion of white (glycolytic) muscle fibres in the muscles of the upper limbs. This greater proportion of white fibres suggests that a greater rate of lactate may be produced by a given muscle mass. Hyperventilation, to blow off CO_2 from the body's bicarbonate buffering stores, occurs in an effort to buffer the lactate produced during exercise. Peak production at termination of the maximum work bout, may be proportionally greater to that of oxygen consumption normally found with leg work.

Vokac et al. (1975), compared the physiological responses of able bodied male subjects to arm and leg work. Respiratory quotients were found to be significantly higher for arm work, VO2L equal to 1.9 L/min. Respiratory frequency was reported to be higher and tidal volume lower during arm work, for the same pulmonary ventilation rate. Subjects were observed to synchronize breathing with stroking frequency.

Blood lactate levels have been reported to be similar during both arm and leg work at maximum effort. Paraplegics reach maximum oxygen uptake at a much lower VO2L than is found with leg work. However, blood lactate levels are reported to be similar (Vokac et al., 1975). The VCO2L should be equivalent to that found during leg work, while oxygen uptake is reported to be about 66% of that found during leg work. Since RQ is a simple ratio of VCO2L to VO2L, this ratio may theoretically be higher during arm work.

Heart rate was found to be significantly correlated to MVO2L at all work intensities. The numerical value of the correlation fell with increased work intensities. As noted previously, HR and many other variables are intercorrelated. The effects of this was noted in the small contribution to the R^2 values in each case.

Subjects with spinal lesion below the thoracic 6-7 level, showed normal maximum HR values. This supports the observation of other investigators

(Knutsson et al., 1973; Wolf & Magora, 1976; Freyschuss & Knutsson, 1969; Freyschuss, 1970; Nilsson et al., 1975).

Subject 02 with a lesion at the Th 5-6 level had an observed maximum heart rate of 189. This is very close to the predicted value for his age, i.e., 220 - age. Although the lesion is above the Th 6-7 level, the inter-individual variations with regard to the level of exit of spinal nerves, or the angle of the lesion may have left some nerves intact at that level, may account for this observation.

Subjects 11 and 12, lesions Th 5 and Th 4-5, respectively, showed what appeared to be partial loss of the sympathetic stimulation to the heart (observed 161, predicted 172; observed 180, predicted 198, respectively).

The variables that contributed to the R^2 values of each equation were similar. The logic determining the use of one variable rather than another appears to be mathematical in nature, rather than based on physiological principles. The P9R program lists many combinations of variables which are only slightly less accurate in the prediction of MVO2L, as compared to the "Best" subset.

The best equations developed at each intensity compared favourably with similar procedures applied to the able bodied population (Hermiston & Faulkner, 1971; Mastropaolo, 1970; Bonen & Babineau, 1977; Metz & Alexander, 1971; Bonen et al., 1979; Fox, 1973). The size of the sample may cast some doubt on the validity of the R^2 values. However, the adj R^2 values are greater and the standard errors of estimate are less than those reported for normal subjects (Bonen et al., 1977; Fox, 1973; Bell et al., 1974; Hermiston & Faulkner, 1971; Jessup et al., 1974; Mastropaolo, 1970; Jette et al., 1976).

Cross validation of the resulting equations was not possible with the sample size available to the study. The use of the deleted press residual gave some indication of the accuracy of prediction that may be found in the population outside the experimental group. A summary of these errors are available in Table 7. It is noted that the LHR intensity did not result in as accurate a prediction as either the MHR and HHR intensities. The absolute mean error was approximately double that found with the equations produced from the higher work intensities.

Table 7. Summary of error associated with the prediction of MVO2L from prediction equations for LHR, MHR, and HHR

Intensity	Method	Mean Residual	Mean absolute Error	CV
HHR	adj del	0.015	13.2%	
	unadj	0.000	6.7%	5.6%
MHR	adj del	0.010	11.8%	
	unadj	0.000	6.6%	5.2%
LHR	adj del	0.020	22.2%	
	unadj	0.000	9.0%	6.5%

The results of analysis of the quadraplegic data must be viewed with the limitation of the sample size taken into consideration. The P:9R program was not utilized for the multiple regression analysis. Difficulty was found with the selection of variables which could be entered into the program. Stepwise multiple correlation analysis was performed and only these results were reported (Table 5).

Correlation analysis suggested physiological relationships, i.e., linear relationships between physiological parameters, observed in able bodied as well as paraplegic subjects, may exist within the quadraplegic sample. Significant correlation coefficients between HR and RQ, HR and VO2ml, Vent and VO2L, Vent and VCO2L, were found (significant at .05 level).

MBC was of particular interest in this group. Since the respiratory muscles of the abdomen and thoracic cage are innervated by nerves exiting from the spinal cord, loss of or reduced capacity to ventilate the lungs (as reflected in MBC), may reflect loss of nervous supply to the heart. In addition, other functional capacities may also be reflected in this measure.

The results suggest significant relationships between MBC and RQ, MBC and HR, MBC and VCO2L. Although these results must be viewed with the limitations specified, they do point to some very interesting differences in the relationships between MBC and certain physiological measures not reported for normals nor paraplegics.

For the quadraplegics, the multiple regression equation developed for the fourth minute of the progressive work protocol (Table 8) produced an adjusted R^2 of .9992, with a standard error of estimate of .0058 l/min. The variables contributing to the equation were: Vent, VO2ml, and WL. Although the adjusted R^2 is formulated to take into account both sample size and the number of variables used in the prediction, it is felt that the value is inflated.

Table 8. Summary of Univariate Statistics for the 4th Minute of Exercise (Quadraplegics)

Variable	Mean	Standard Deviation
MBC	130.4	16.1
WL	206.6	17.6
HR	105.0	18.4
VO2L	0.606	0.057
VO2ml	9.35	1.30
VC O2L	0.531	0.081
VCO2ml	8.25	1.41
RQ	0.886	0.087
Vent	20.1	5.17

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purposes of this investigation were, firstly, to determine which of certain structural and functional characteristics of quadraplegics and paraplegics were significantly related to MVO2L. Secondly, to utilize multiple regression analysis to determine and combine the best five predictors into a multiple regression equation for the prediction of MVO2L.

Preliminary investigation indicated that the two subgroups, quadraplegics and paraplegics could not be equated on either submaximal workloads or the physiological responses to these. The group of 18 physically disabled subjects were divided into two sub-groups for analysis.

Analysis of three work intensities was carried out on the paraplegic data. These corresponded to: 70%, 75%, and 80% of the mean maximum heart rate for the group. Increasing numbers of variables were found to be significantly related to MVO2L, with increased work intensities. Multiple regression analysis supported these findings. The two higher work intensities produced more accurate prediction equations than the lowest intensity. The adjusted press absolute mean error, illustrated that the error for subjects outside the experimental group will average 22%, with the LHR equation. This error was reduced to 13.2% and 11.8% for HHR and MHR, respectively.

The analysis of the quadraplegic data was restricted to the physiological responses to the WL at the fourth minute of the progressive continuous workload protocol. Due to the small sample size, interpretations and conclusions are not justified. However, some interesting relationships were reported.

Conclusions

1. Multiple regression analysis appeared to be a suitable method of developing accurate prediction equations for MVO2L, in paraplegic subjects.
2. Accuracy in prediction of maximum oxygen uptake in the paraplegic population, is increased with the increase in physiological stress (as reflected in % of maximum heart rate) the subject is subjected to.
3. Due to the limited sample size, no conclusions were made regarding prediction of MVO2L within the quadraplegic population.

Recommendations for Further Research

The area of prediction of maximum oxygen uptake with the physically disabled population is virtually unexplored. The present study is the first of its kind. Thus the area is wide open. Some specific research is suggested:

1. Determination of a valid method of estimating fat free weight, is required. Many of the subjects were overweight causing problems with the interpretation of MVO2ml and the correlation coefficients involving body weights.
2. It is recommended that the protocol for workload adjustment be modified to increase the duration to 2 minutes at each workload.
3. Validation of the prediction equations developed for the paraplegics is necessary.
4. The results of the analysis of the quadraplegic data has indicated promising results. This study should be continued with greater numbers of

quadraplegics, so that conclusions are possible.

5. Differences, if any should be determined for the prediction of maximum oxygen uptake with individuals who vary in the type of disability, i.e., polio, bone diseases, amputees, etc.
6. The above should be conducted for physically disabled females.

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APPENDIX A

The Wheelchair Ergometer

Wheelchair Ergometer

The ergometer was designed so that each subject could utilize his own wheelchair. It consisted of three steel rollers 3 inches in diameter and 30 inches in length. The center roller was fixed in position while the outer two were suspended by springs. The two outer rollers served the purpose of accepting much of the weight of the subject and chair and to stabilize the chair against forward and backwards rocking during the stroking.

The loading system of a Monarch bike was adapted and utilized to apply resistance to the middle roller. The friction strap which normally was placed around the flywheel of the bike was placed around the center roller of the wheelchair ergometer. Resistance was adjusted and read from the pendulum indicator as it would be with the normal bike ergometer. However, internal resistance had to be taken into account.

Internal resistance is that within the roller system and the indentation of the pneumatic tire caused by the rollers. This value is varied on both tire pressure and weight of the subject. This resistance was measured at a constant tire pressure of 50 pounds per square inch. The force required to cause movement of the wheelchair wheels was determined for a variety of weights placed in the wheelchair. Increasing weight was hung vertically at a right angle from the outer perimeter of one wheel until movement was initiated.

Internal resistance was plotted against weight in the wheelchair. This produced a curvilinear line. For each subject internal resistance was read from the graph. Exercise resistances were achieved by adding the necessary resistance via the load adjuster, to the internal resistance.

During exercise the wheelchair had to be further secured with small gauge chains to prevent rocking as the subjects stroked at higher workloads. The chains were secured around the front casters of the wheelchair and fastened to the wooden frame of the ergometer.

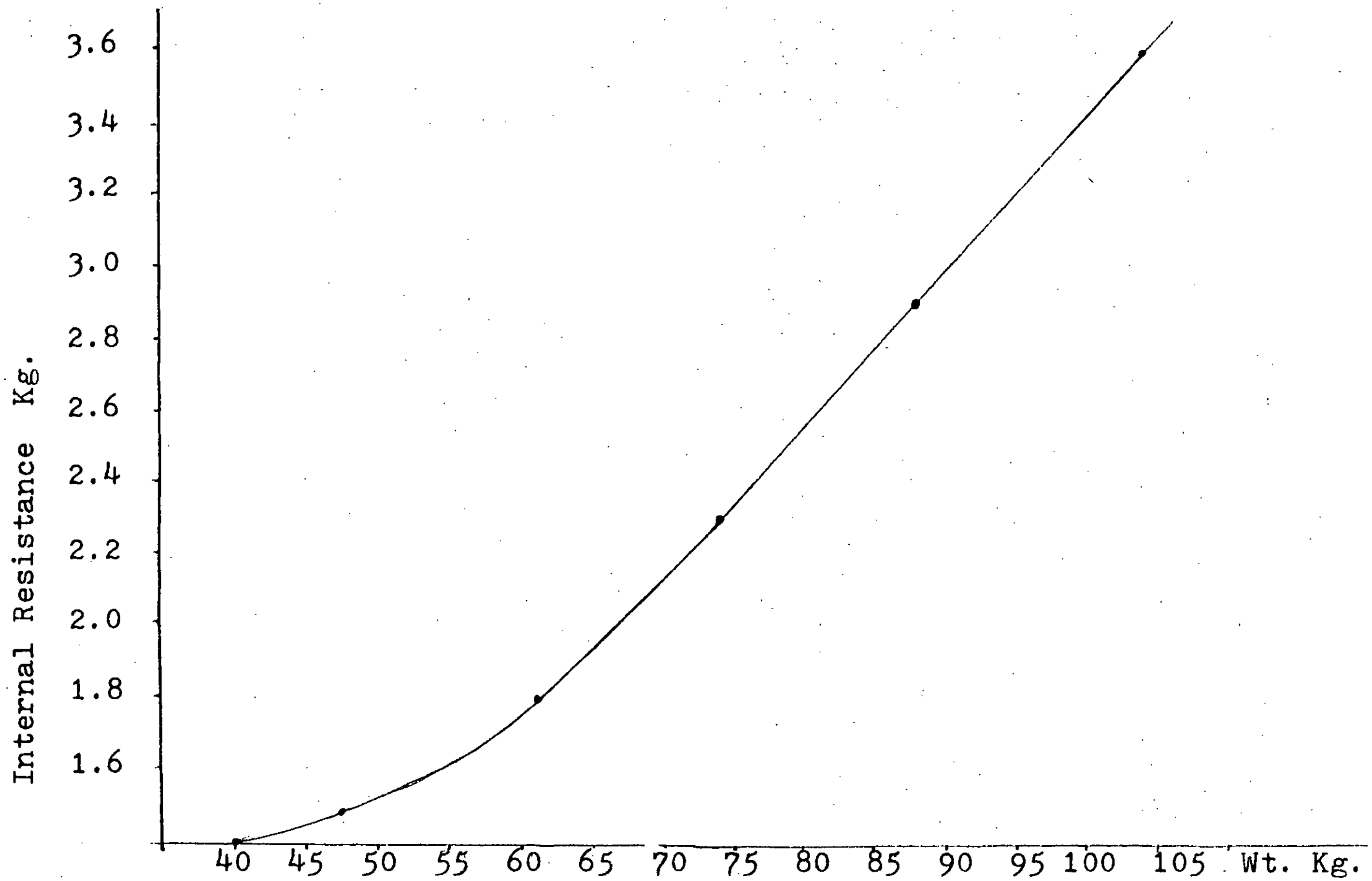
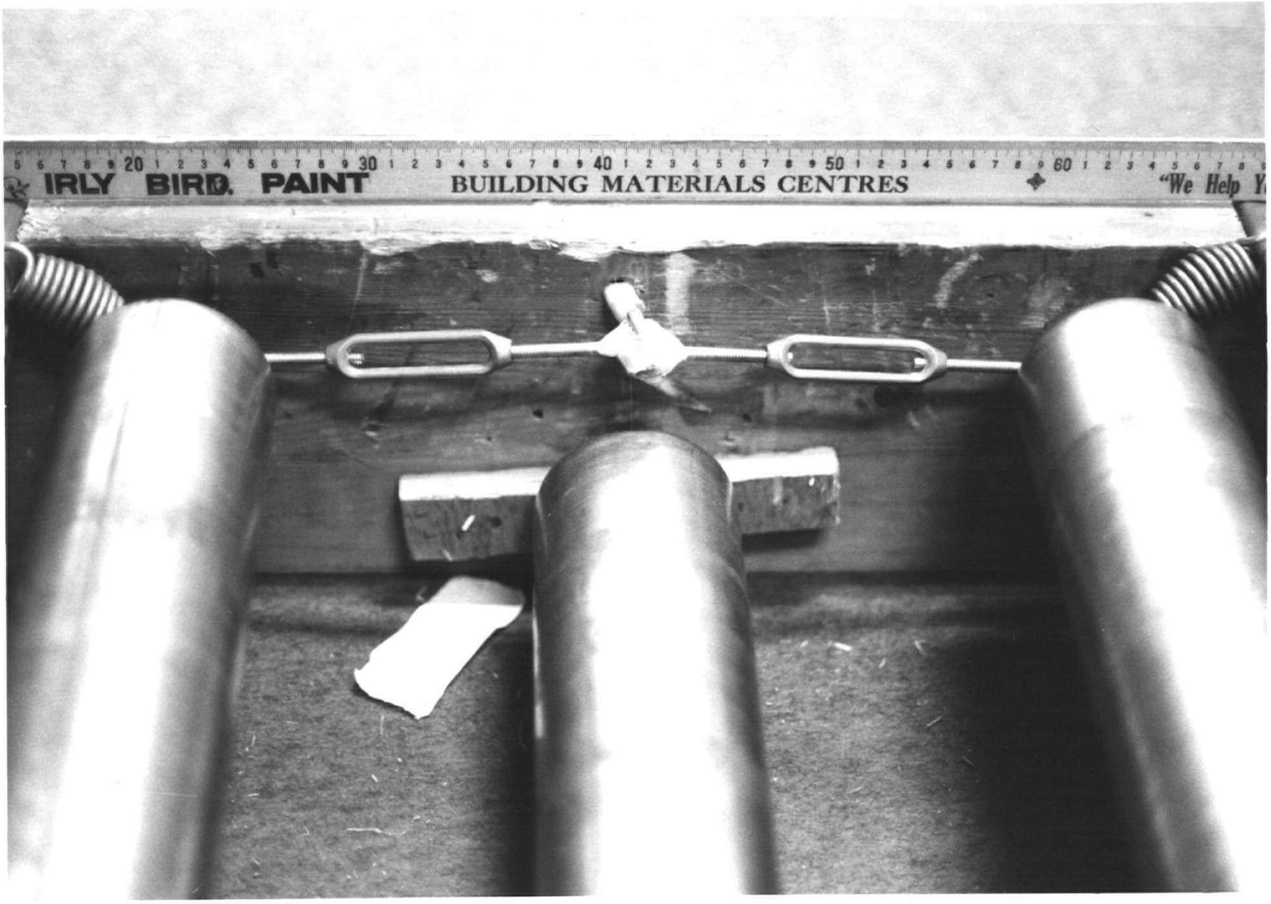


Figure 7 Internal Resistance vs Weight in Wheelchair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APPENDIX B

Individual Cardiorespiratory Responses to the Workload Protocol

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
01	79.3	168	38	110	089	0.491	06.19	0.186	03.60	0.58	011.10	1.912
				189	092	0.724	09.12	0.406	05.12	0.56	014.70	
				208	090	0.638	08.03	0.399	05.03	0.63	012.80	
				231	096	0.788	09.93	0.510	06.43	0.65	015.70	
				228	098	0.757	09.54	0.534	06.72	0.71	014.90	
				280	102	0.826	10.40	0.628	07.91	0.77	016.90	
				352	110	0.961	12.10	0.751	09.46	0.78	019.40	
				*368	122	1.135	14.30	0.969	12.20	0.86	025.25	
				*409	130	1.278	16.10	1.143	14.40	0.90	019.00	
				*423	145	1.532	19.30	1.461	18.40	0.96	038.00	
				564	165	1.858	23.40	2.088	26.30	1.13	080.00	
				568	175	1.898	23.90	2.390	30.10	1.28	076.00	
				511	185	1.842	23.20	2.342	29.65	1.29	085.00	
02	78.0	180	38	106	088	0.440	05.64	0.250	03.20	0.57	010.40	1.774
				157	092	0.499	06.40	0.300	03.84	0.60	011.14	
				158	095	0.548	07.03	0.356	04.56	0.65	012.80	
				215	106	0.693	08.89	0.497	06.37	0.72	016.70	
				*269	118	0.771	09.89	0.555	07.12	0.72	017.60	
				*360	132	0.970	12.44	0.797	10.22	0.82	023.33	
				*420	142	1.009	12.94	0.906	11.62	0.90	025.38	
				595	159	1.225	15.70	1.169	14.99	0.96	032.94	
				579	175	1.440	18.46	1.580	20.26	1.10	046.48	
				600	185	1.774	22.75	2.338	29.97	1.32	084.24	
03	95.5	250	53	138	084	1.030	10.79	0.858	08.98	0.82	024.90	2.158
				117	090	0.945	09.90	0.783	08.20	0.76	023.80	
				106	096	0.864	09.05	0.640	06.70	0.75	021.60	
				226	105	1.024	10.72	0.784	08.21	0.76	024.90	

*Indicates lines of data selected for regression analysis

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
				188	100	1.290	13.51	0.987	10.34	0.77	029.71	
				275	125	1.226	12.84	1.012	10.60	0.82	029.80	
				*318	125	1.220	12.78	1.003	10.50	0.82	028.20	
				*340	130	1.369	14.34	1.203	12.60	0.84	032.15	
				*445	135	1.662	17.40	1.413	14.80	0.86	041.50	
				511	140	1.583	16.60	1.375	14.40	0.86	042.40	
				530	150	1.891	19.80	1.671	17.50	0.88	050.40	
				500	160	2.063	21.60	1.900	19.90	0.92	056.90	
				368	165	2.158	22.60	1.995	20.90	0.92	061.30	
04	87.5	129	38	127	101	0.630	07.20	0.595	06.80	0.94	023.60	
				127	102	0.800	09.14	0.744	08.50	0.90	026.60	
				148	102	0.656	07.50	0.595	06.80	0.90	024.00	
				191	106	0.621	07.10	0.586	06.70	0.94	021.80	
				233	121	0.770	08.80	0.674	07.70	0.86	023.80	
				292	130	1.085	12.40	1.083	12.38	1.01	037.74	
				275	142	1.251	14.30	1.444	16.50	1.16	046.80	
				398	142	1.108	12.67	1.278	14.60	1.16	039.70	
05	56.0	186	18	072	111	0.558	09.97	0.402	07.19	0.72	012.90	2.285
				105	116	0.611	10.91	0.470	08.40	0.77	014.90	
				148	125	0.683	12.20	0.538	09.60	0.78	016.40	
				191	135	0.796	14.22	0.633	11.30	0.80	019.00	
				233	139	0.900	16.07	0.706	12.60	0.78	020.03	
				292	143	0.963	17.20	0.773	13.80	0.80	022.50	
				*350	145	1.114	19.90	0.907	16.20	0.82	024.80	
				*413	153	1.170	20.90	1.002	17.90	0.86	027.00	
				*477	162	1.428	25.50	1.254	22.40	0.88	033.40	
				556	172	1.579	28.20	1.602	28.60	1.01	040.70	
				636	181	1.725	30.80	1.860	33.21	1.08	048.00	
				715	192	2.005	35.80	2.261	40.37	1.13	060.00	
				795	192	2.110	37.69	2.486	44.40	1.18	068.20	
				874	202	2.285	40.80	2.620	46.80	1.15	074.30	

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
06	54.0	138	22	086	082	0.442	08.18	0.380	07.04	0.86	010.10	0.792
				081	087	0.511	09.46	0.441	08.16	0.85	012.00	
				144	094	0.513	09.50	0.454	08.40	0.89	012.80	
				233	099	0.520	09.63	0.455	08.43	0.88	013.30	
				289	099	0.759	14.05	0.657	12.16	0.88	018.00	
				326	104	0.792	14.67	0.772	14.30	0.97	021.70	
				268	105	0.750	13.90	0.801	14.84	1.11	034.40	
07	70.6	125	29	091	090	0.395	05.60	0.282	04.00	0.70	008.76	1.673
				115	086	0.504	07.14	0.266	05.18	0.72	011.12	
				152	097	0.443	06.27	0.336	04.76	0.76	010.10	
				209	098	0.518	07.34	0.394	05.58	0.76	011.40	
				262	109	0.591	08.37	0.459	06.50	0.78	013.80	
				284	115	0.788	11.17	0.641	09.08	0.82	016.60	
				*366	130	0.870	12.33	0.768	10.88	0.89	020.40	
				*443	132	1.011	14.23	1.005	14.23	1.00	026.10	
				*504	161	1.334	18.89	1.461	20.70	1.09	039.60	
				598	175	1.358	19.23	1.627	23.40	1.20	047.80	
				602	180	1.553	22.14	1.920	27.20	1.22	063.40	
				738	181	1.673	23.70	2.066	29.26	1.24	068.70	
08	61.7	106	25	080	120	0.750	12.15	0.648	10.50	0.86	024.00	1.185
				099	130	0.580	09.40	0.600	09.72	1.03	023.90	
				211	134	0.586	09.50	0.584	09.46	0.99	024.80	
				204	135	0.654	10.60	0.645	10.45	0.99	027.30	
				225	136	0.827	13.40	0.823	13.34	0.99	032.60	
				239	140	0.833	13.50	0.913	14.80	1.09	037.10	
				286	140	1.012	16.40	1.174	19.03	1.16	048.70	
				264	139	1.185	19.20	1.252	20.30	1.25	048.30	

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
09	69.0	206	31	154	095	0.545	06.90	0.321	04.06	0.60	011.30	2.280
				175	101	0.664	08.40	0.389	04.92	0.68	012.40	
				218	101	0.742	09.39	0.465	05.89	0.62	014.80	
				267	111	0.890	11.26	0.590	07.47	0.66	017.90	
				353	118	0.059	13.40	0.717	09.08	0.68	021.40	
				438	131	1.270	16.07	0.940	11.90	0.74	027.80	
				*459	133	1.480	18.70	1.160	14.70	0.79	032.22	
				*536	140	1.550	19.60	1.340	16.93	0.86	037.20	
				*592	146	1.720	21.80	1.580	20.00	0.92	044.90	
				727	160	1.710	21.60	1.596	20.20	0.94	045.60	
				636	167	1.960	24.80	1.830	23.20	0.94	055.60	
				693	176	2.280	28.80	2.430	30.78	1.08	077.50	
10	70.0	243	26	149	085	0.728	10.40	0.495	07.04	0.68	012.60	2.849
				254	101	0.927	13.24	0.666	09.52	0.72	018.10	
				300	101	0.987	14.10	0.802	11.46	0.82	020.20	
				387	107	1.078	15.40	0.854	12.20	0.80	021.10	
				417	113	1.211	17.30	1.029	14.70	0.84	025.00	
				427	117	1.246	17.80	1.106	15.80	0.89	026.80	
				481	121	1.435	20.50	1.274	18.20	0.89	030.20	
				*527	135	1.582	22.60	1.484	21.20	0.94	034.60	
				*573	154	1.834	26.20	1.834	26.20	1.00	041.60	
				*670	165	2.219	31.70	2.380	34.00	1.08	053.50	
				680	170	2.303	32.90	2.555	36.50	1.11	058.50	
				793	180	2.583	36.90	3.045	43.50	1.18	073.80	
				772	185	2.849	40.70	3.346	47.80	1.18	083.10	

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
11	91.8	106	48	136	088	0.863	09.40	0.780	08.50	0.90	021.40	1.970
				150	087	0.964	10.50	0.815	08.88	0.85	022.80	
				138	090	0.861	09.38	0.688	07.50	0.89	018.50	
				203	089	0.863	09.40	0.732	07.97	0.85	018.40	
				280	101	0.909	09.90	0.799	08.70	0.88	020.50	
				*356	111	0.991	10.80	0.909	09.90	0.92	023.30	
				*532	132	1.320	14.40	1.240	13.50	0.94	031.10	
				*404	148	1.560	17.00	1.625	17.70	1.04	040.80	
				400	161	1.970	21.50	2.313	25.20	1.17	072.00	
12	62.1	198	22	139	088	0.766	12.34	0.545	08.78	0.72	014.90	2.640
				189	095	0.900	14.50	0.621	10.00	0.69	016.70	
				197	095	0.807	13.00	0.602	09.70	0.75	015.70	
				226	098	0.851	13.70	0.658	10.60	0.78	016.80	
				292	106	1.049	16.90	0.795	12.80	0.76	017.77	
				388	116	1.186	19.10	0.919	14.80	0.78	022.00	
				392	125	1.292	20.80	1.059	17.06	0.82	024.90	
				434	129	1.534	24.70	1.298	20.90	0.85	029.70	
				523	132	1.590	25.60	1.453	23.40	0.92	033.50	
				*550	149	1.652	26.60	1.528	24.60	0.94	035.00	
				*654	160	1.906	30.70	1.913	30.80	1.02	045.00	
				*718	166	2.322	37.40	2.496	40.20	1.08	061.10	
				757	179	2.360	38.00	2.875	46.30	1.24	081.00	
				782	180	2.640	42.50	3.173	51.10	1.22	092.00	
13	65.0	156	52	089	087	0.748	11.50	0.500	07.70	0.66	014.90	1.580
				156	089	0.693	10.60	0.533	08.20	0.76	013.90	
				160	093	0.783	12.50	0.670	10.30	0.76	019.40	
				203	094	0.741	11.40	0.658	10.12	0.89	018.40	
				290	102	1.060	17.46	1.060	16.31	0.93	026.00	
				339	110	1.222	18.80	1.313	20.20	1.09	034.20	
				*368	116	1.262	19.40	1.378	21.20	1.09	036.20	

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
				*348	130	1.398	21.50	1.684	25.90	1.21	045.90	
				*409	137	1.436	22.10	1.801	27.70	1.26	055.50	
				438	145	1.580	24.30	1.944	29.09	1.23	062.00	
14	66.9	150	37	089	068	0.278	05.76	0.268	04.00	0.70	013.00	1.024
				092	073	0.506	07.57	0.332	04.96	0.66	014.00	
				164	078	0.530	07.92	0.389	05.82	0.74	016.40	
				241	083	0.656	09.80	0.476	07.42	0.76	020.00	
				227	085	0.763	11.40	0.594	08.88	0.78	023.80	
				262	091	0.727	10.87	0.605	09.05	0.83	025.60	
				277	094	0.777	11.61	0.726	10.86	0.94	031.40	
				177	095	1.024	15.31	1.084	16.20	1.06	050.80	
15	84.0	150	33	143	086	0.659	07.84	0.512	06.10	0.79	014.90	2.612
				124	083	0.659	07.84	0.521	06.20	0.80	015.40	
				175	092	0.692	08.24	0.554	06.60	0.81	016.20	
				224	094	0.756	09.00	0.618	07.36	0.83	018.00	
				267	098	0.916	10.90	0.753	08.96	0.83	021.00	
				347	105	0.949	11.30	0.774	09.22	0.82	021.10	
				377	112	1.151	13.70	0.943	11.22	0.82	025.00	
				515	118	1.235	14.70	1.075	12.80	0.88	029.00	
				561	120	1.445	17.20	1.302	15.50	0.90	035.00	
				*582	130	1.579	18.80	1.478	17.60	0.94	039.00	
				*592	133	1.730	20.60	1.630	19.40	0.95	044.50	
				*704	145	1.982	23.60	1.966	23.40	1.00	057.00	
				861	168	2.453	29.20	2.755	32.80	1.14	090.00	
				850	180	2.612	31.10	3.167	37.70	1.23	111.50	
16	64.0	129	21	085	080	0.387	06.04	0.336	05.25	0.87	010.70	2.195
				127	084	0.454	07.09	0.371	05.80	0.82	012.10	
				148	093	0.561	08.76	0.461	07.20	0.82	014.30	
				191	102	0.531	08.30	0.420	06.56	0.79	013.50	

Sub	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml	RQ	Vent L	MVO2 L
				233	118	0.730	11.40	0.580	09.07	0.79	017.40	
				291	125	0.890	13.90	0.705	11.02	0.79	020.60	
				350	130	1.152	18.00	1.004	15.69	0.87	027.60	
				413	131	1.197	18.70	1.119	17.42	0.94	031.10	
				*477	144	1.264	19.74	1.196	18.69	0.94	031.90	
				*557	150	1.330	20.80	1.307	20.42	0.98	035.30	
				*636	165	1.754	27.40	1.843	28.80	1.05	051.00	
				716	182	1.933	30.20	2.500	39.06	1.30	077.10	
				795	202	2.195	34.30	3.268	51.06	1.50	124.00	
17	60.0	129	21	072	075	0.332	05.54	0.245	04.08	0.74	020.21	
				106	083	0.416	06.93	0.322	05.36	0.88	014.16	
				149	091	0.494	08.23	0.681	05.99	0.78	016.89	
				191	100	0.580	09.66	0.494	08.24	0.86	017.64	
				233	109	0.847	14.12	0.868	14.47	1.03	027.50	
				291	114	0.846	14.10	0.973	16.21	1.16	033.46	
				349	110	0.742	12.36	1.080	18.00	1.46	028.40	
18	53.0	134	35	087	098	0.143	02.70	0.099	01.87	0.69	005.80	1.780
				087	098	0.378	07.14	0.251	04.73	0.66	011.60	
				148	107	0.514	09.70	0.343	06.48	0.67	012.60	
				191	113	0.659	12.43	0.463	08.75	0.70	015.72	
				*233	118	0.668	12.61	0.531	10.02	0.80	016.70	
				*291	131	0.960	18.11	0.814	15.36	0.85	025.22	
				*350	135	1.090	20.56	1.00	18.86	0.92	030.00	
				413	170	1.510	28.49	1.535	28.97	1.02	045.50	
				477	175	1.600	30.18	1.866	35.20	1.16	059.12	
				557	180	1.780	33.58	2.120	40.01	1.19	070.86	
				636	180	1.716	32.38	1.913	35.90	1.11	068.20	

APPENDIX C

Correlation Matrices

Correlation Matrix: LHR Group

	1 Wt	2 MBC	3 AG	4 WL	5 HR	6 VO2L	7 VO2ml	8 VCO2L	9 VCO2ml
1	1.000								
2	0.115	1.000							
3	0.632	-0.023	1.000						
4	0.218	0.439	-0.220	1.000					
5	-0.411	0.432	-0.683	0.542	1.000				
6	0.119	0.620	-0.104	0.926	0.528	1.000			
7	-0.517	0.205	-0.560	0.602	0.740	0.624	1.000		
8	0.081	0.456	-0.017	0.889	0.405	0.947	0.660	1.000	
9	-0.455	0.301	-0.332	0.640	0.559	0.737	0.864	0.834	1.000
10	-0.069	-0.207	0.187	0.372	-0.068	0.370	0.425	0.642	0.660
11	0.187	0.503	0.167	0.825	0.393	0.914	0.563	0.932	0.695
12	0.013	0.530	-0.513	0.826	0.600	0.784	0.571	0.673	0.569
13	-0.656	0.289	-0.796	0.409	0.749	0.445	0.763	0.406	0.721

	10 RQ	11 Vent L	12 MVO2L	13 MVO2ml
10	1.000			
11	0.520	1.000		
12	0.065	0.535	1.000	
13	0.106	0.232	0.713	1.000

Correlation Matrix: MHR Group

	1 Wt	2 MBC	3 AG	4 MVO2L	5 MVO2ml	6 WL	7 HR	8 VO2L	9 VO2ml
1	1.000								
2	0.115	1.000							
3	0.632	-0.023	1.000						
4	0.013	0.530	-0.513	1.000					
5	-0.656	0.290	-0.796	0.713	1.000				
6	-0.028	0.195	-0.588	0.784	0.526	1.000			
7	-0.152	0.217	-0.576	0.667	0.630	0.713	1.000		
8	0.276	0.375	-0.102	0.763	0.332	0.801	0.658	1.000	
9	-0.308	0.314	-0.471	0.767	0.731	0.783	0.784	0.809	1.000
10	0.212	0.216	0.005	0.588	0.259	0.706	0.613	0.950	0.816
11	-0.249	0.191	-0.283	0.552	0.565	0.688	0.695	0.790	0.957
12	-0.017	-0.269	0.179	-0.051	-0.036	0.279	0.282	0.469	0.506
13	0.169	0.141	0.055	0.507	0.211	0.634	0.526	0.858	0.730

	10 VCO2L	11 VCO2ml	12 RQ	13 Vent L
10	1.000			
11	0.880	1.000		
12	0.714	0.728	1.000	
13	0.924	0.811	0.700	1.000

Correlation Matrix: HHR Group

	1 Wt	2 MBC	3 AG	4 MVO2L	5 MVO2ml	6 WL	7 HR	8 VO2L	9 VO2ml
1	1.000								
2	0.115	1.000							
3	0.632	-0.023	1.000						
4	0.013	0.530	-0.513	1.000					
5	-0.656	0.289	-0.796	0.713	1.000				
6	0.034	0.161	-0.528	0.834	0.537	1.000			
7	-0.484	0.174	-0.878	0.525	0.716	0.603	1.000		
8	0.007	0.481	-0.384	0.873	0.602	0.860	0.558	1.000	
9	-0.525	0.316	-0.659	0.718	0.885	0.690	0.750	0.827	1.000
10	-0.118	0.328	-0.347	0.714	0.564	0.809	0.585	0.924	0.854
11	-0.506	0.219	-0.540	0.586	0.765	0.656	0.708	0.791	0.962
12	-0.284	-0.915	0.001	-0.066	0.100	0.244	0.286	0.315	0.423
13	-0.083	0.490	-0.244	0.651	0.497	0.539	0.460	0.694	0.609

	10 VCO2L	11 VCO2ml	12 RQ	13 Vent L
10	1.000			
11	0.902	1.000		
12	0.610	0.649	1.000	
13	0.743	0.647	0.441	1.000

Correlation Matrix: Quadraplegic Group

	Wt	MBC	AG	WL	HR	VO2L	VO2ml	VCO2L	VCO2ml
1	1.000								
2	0.012	1.000							
3	0.823	0.375	1.000						
4	-0.596	0.398	-0.224	1.000					
5	-0.025	-0.978	-0.310	-0.247	1.000				
6	0.458	-0.225	0.610	-0.459	0.261	1.000			
7	-0.860	-0.197	-0.596	0.404	0.236	0.055	1.000		
8	0.427	-0.854	0.160	-0.524	0.873	0.596	-0.091	1.000	
9	-0.629	-0.729	-0.656	0.173	0.768	0.079	0.792	0.433	1.000
10	0.185	-0.906	-0.239	-0.293	0.912	0.035	-0.126	0.822	0.506
11	0.384	-0.648	0.338	-0.500	0.682	0.881	0.100	0.892	0.397
12	0.775	-0.443	0.665	-0.515	0.493	0.774	-0.402	0.843	-0.033
13	-0.218	-0.711	-0.417	0.049	0.807	0.534	0.590	0.705	0.843

	10 RQ	11 Vent L	12 MVO2L	13 MVO2ml
10	1.000			
11	0.489	1.000		
12	0.499	0.852	1.000	
13	0.524	0.768	0.448	1.000