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AN INVESTIGATION OF THE VALIDITY  
OF A SECTION OF A THEORETICAL MODEL  
TO PREDICT WORK PHYSIOLOGY PARAMETERS  
FROM AGE AND WEIGHT

A RESEARCH REPORT PRESENTED IN PARTIAL  
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ABSTRACT

Work physiology is the study of physiological parameters of the body during work. Two of these physiological parameters are commonly measured to assess the cost of work : oxygen consumption and heart rate.

In 1979 a theoretical model was developed to estimate some ergonomic parameters from age, height and weight. While this model predicted anthropometric, biomechanical and work physiology parameters, the present research was concerned only with the section of the model predicting work physiology parameters of oxygen consumption and heart rate from age and weight.

In this study oxygen consumption and heart rate values were obtained from measurement of seven subjects working on an ergometer. These values were then used to test three of the equations in the predictive model. Two of the equations were found to be unreliable as predictors of oxygen consumption and heart rate for this sample, while one of the equations was found to be reliable. Further research with a larger sample is necessary before any firm conclusions about this section of the model may be made.

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## CHAPTER 1

### Introduction

"Manual labour, sometimes under adverse environmental conditions, still exists in all countries, and will probably remain an essential part of the society. Furthermore, individuals continue to find satisfaction and enjoyment in their leisure time through sports or other types of muscular activity . . . In a very broad sense, physical performance or fitness is determined by the individual's capacity for energy output (aerobic and anaerobic processes and oxygen transport), neuromuscular function (muscle strength, co-ordination and technique), joint mobility and psychological factors (e.g. motivation and tactics) These factors play a more or less dominating role depending upon the nature of the performance" (Astrand and Rodahl, 1977, 7).

So interest in the physical capacity of individuals to perform, whether at work or leisure, has increased in spite of a corresponding increase in automation in the work place. Indeed Davis (1977) doubts that automation will continue at the exponential level predicted.

Davis (1977) identified three stages of technological progress; Primary (simple), Secondary (complex, non human energy) and Tertiary (fully automatic), and stated that during its formative years ergonomics had concerned itself with looking at Secondary systems. However the need to investigate primary technology is now perceived to be of increasing importance because of the

possibility of an initial rise in manual worker availability following the turn of the next century, followed by a rapid fall. The rationale for the perceived need for the redesign and improved knowledge of primary technology is that as energy supplies diminish there will be a need to return to biological energy, but with the present levels of population there is insufficient land to support any large increases in horses or cattle as alternative energy sources. If, therefore, manual labour and other physical activities are to become the focus of future concentration it is necessary that we know as much as possible about work, the physical cost of work, the measurement of that cost, and how work can be efficient within the physical limits of the individual.

The objective of this research report is to test some theoretical models developed to determine physical performance, based on heart rate and oxygen consumption, against direct measures of these parameters.

### 1.1 Body Work and Energy

The physiology of muscular work and exercise is basically a matter of transforming bound energy into mechanical energy. Many similarities exist between the "human engine" and the combustion engine constructed by human beings. In the combustion engine petroleum and air are introduced into the cylinder.

The spark from the spark plug initiates the explosive combustion of the gas mixture. Chemical energy is transformed into kinetic energy and heat.

The expansion of the gas forces the piston to move, and a system of mechanical devices can transfer this motion to the wheels. The motor is cooled by fluid or air to prevent overheating. The waste products are expelled with the exhaust. As this motor can work only in the presence of oxygen, its function is aerobic. When the petrol tank is empty, the engine can no longer continue to run, since the operation of the combustion engine is dependent upon a continuous supply of fuel. In a motorcar, the starter motor provides the energy for the first movements of the pistons. This energy comes from the battery which accumulates electrical energy : the starter can thus work in the absence of oxygen, or anaerobically. The stored energy of the battery is quite limited however, so the battery must be frequently recharged.

"Living organisms, like machines, conform to the law of the conservation of energy, and must pay for all their activities in the currency of metabolism (Baldwin, 1967). In the human machine, the muscle fibers (sic) are the pistons. When fuel is available and a spark is introduced to start the breaking down of the fuel, part of the energy which is thus liberated can cause movement of the pistons. Heat and various waste products are produced" (Astrand and Rodahl, 1977, 12).

The energy needs of individuals are satisfied by food which the individual consumes during the course of a day. If the health and activity of individuals are to be maintained then a certain minimum amount of food must be consumed per day.

However, the problem arises of how to measure the amount of food consumed and what proportion of this food is converted into energy and used as such in the human engine.

### 1.2 Direct Measures of Energy Expenditure

Obviously dietary studies can be made of individual subjects and this has been attempted in the past. The energy expenditure of a variety of occupations was stated after analysing the diets consumed by individuals of known employment (Voit et al, 1955). This method is open to the theoretical objection that it assumes that the diets consumed provide exactly enough energy with no surplus or deficiency (Passmore and Durnin 1955). It provides no direct yardstick or requirement. Indeed, especially in developing countries large numbers of people certainly have an insufficiency of food for health and activity, whereas the high incidence of obesity in Western countries shows that many consume regularly an excess of food over their physical requirements.

There is a real difficulty in converting the results of dietary surveys into tables of food requirements. Further, dietary surveys are always difficult and expensive to carry out. This particularly applies to individual surveys which provide so much more information than the less precise family surveys (Passmore and Durnin, 1955).

### 1.3 Indirect Measures of Energy Expenditure

Alternatively, the use of rates of oxygen consumption as the basis for measuring energy expenditure has become widely used. This method of measuring the metabolic cost of work, along with heart rate, is known as indirect calorimetry and has been increasingly used in field conditions, to a large part due to the development of apparatus which may now be used in field conditions, whereas it was once impracticable to do this because of the cumbersome nature of the apparatus designed for studies in laboratory conditions.

Indirect calorimetry enables the energy expended to be determined while a definite activity is undertaken for a limited period of time, usually measured in minutes. In the past indirect calorimetry and data collected using this method have met with only limited success, mainly due to the practical difficulties of determining oxygen consumption in field settings. The apparatus that was used in earlier attempts to establish energy expenditure at work was the Douglas Bag, the size of which made studies under field conditions very difficult and led to imprecise data collection. The Douglas Bag was more suited to static exercise, or treadmill running in the laboratory. However in the 1940's a light portable respirometer was developed at the Max-Planck-Institut für Arbeitsphysiologie in Germany. The portable respirometer has several attributes in its favour over the Douglas Bag for experiments under field conditions. It is light, weighs less than four kilograms;



it can be worn on the back like a haversack; it measures the volume of expired air directly while simultaneously diverting a small fraction of the expired air (0.3 - 6%) into a rubber bladder for later analysis (Passmore and Durnin, 1955).

Passmore and Durnin (1955) state that first major test of the portable respirometer was a survey of workers in German industry during World War two. Observations were made of individuals only at work in the factories and the mines, but assumptions were made for energy expenditure outside working time and the results were expanded and expressed in terms of daily energy requirements. Subsequent observations were carried out in Britain and from these, tables of energy expenditure for given occupations and activities have been compiled.

It is interesting to note that even though the portable respirometer, and various modifications, has been in use for approximately forty years at the time of writing, there is still a dependence on laboratory work with the Douglas Bag. While it may be assured that the portable respirometer would be technically superior and more accurate than the Douglas Bag, Astrand and Rodahl (1977) disagree. "The classical method for the determination of oxygen uptake, the Douglas Bag method, rests on a very secure foundation. It is theoretically sound, and it is well tested under a wide variety of circumstances. In all its relative simplicity, it is unsurpassable in accuracy" (p. 339).

Examples of the continued use of the Douglas Bag may be seen in the work of Vokac et al (1975), Bergh et al (1976), Goldsmith et al (1978) and Datta et al (1978). On the other hand Aunola et al (1978), Soule et al (1978), Saha et al (1979) and Verma et al

(1979) used a portable respirometer to collect expired air for analysis to determine energy expenditure in their experiments.

It is felt that the measurement of oxygen consumption in order to estimate an individual's energy expenditure can give rise to imprecision. An opinion is (Passmore and Durnin, 1955) that larger errors are likely to arise from a failure to determine correctly the length of time spent in any activity rather than in any assessment of the metabolic cost of that activity. An example of this is that if a man walks to and from his work every day, it is essential to know how long he spends on the journey. When compared with his other activities the exact energy cost of the walking may be comparatively unimportant. Further, one measurement of such an activity is only strictly applicable to the walking while the measurement is being made. An accurate value for an individual's walking, in general, necessitates several estimations under a variety of environmental conditions (Passmore and Durnin, 1955).

For this reason one must seriously consider the implications of the use of oxygen consumption from which to measure individuals' energy expenditure. If, however, the alternative is direct calorimetry through a study of individuals' diets, then the measurement of oxygen consumption is preferable for research purposes. However it must be stressed that no single tool exists than can measure the effects of different kinds of loads on an individual (Davis et al, 1969), which leads to a second physiological variable that must be examined : heart rate.

Heart rate is used to measure energy expenditure indirectly for a variety of reasons. It is less intricate and time consuming than the measurement of oxygen consumption, the use of which has been felt to retard progress in the determination of energy expenditure at work (Leblanc, 1957). Further, oxygen consumption alone is not a reliable indicator of energy expenditure (Maxfield and Brouha, 1963). There is a linear relationship between heart rate and oxygen consumption (Astrand and Rodahl, 1977), and it is felt wise to measure both heart rate and oxygen consumption since oxygen consumption alone would not indicate changes in temperature and humidity in the work environment (Davis et al, 1969). Finally, heart rate has been shown to be sufficiently accurate within the range of most industrial jobs (Ricci, 1967).

However in his research the central concern is the cost of work and the capabilities and limitations of individuals.

## CHAPTER 2

### The Cost of Work and Its Estimation

The physiological cost of work is the energy that the individual expends while performing the work. It may be seen as the absolute cost of work, expressed as the cost, or as the relative cost of work compared to the individual's maximum capacity. In other words the cost of work may be expressed either as the absolute cost in litres of oxygen per minute, or in kilocalories or in watts; or it may be expressed as a percentage of the individual's potential (maximum) capacity or workload. Because of this, the treatment of the estimation of the cost of work must be concerned with Aerobic and Anaerobic processes, i.e. oxygen consumption during submaximal and maximal exercise and the individual's maximal oxygen consumption.

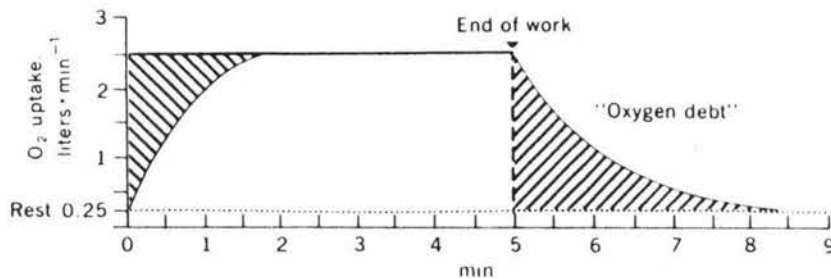
#### 2.1 Aerobic Processes

"For each liter (sic) of  $O_2$  consumed, about 20 kilojoules (of energy) will be delivered; hence, the higher the oxygen uptake, the higher the energy output. The oxygen uptake during exercise may be measured with an accuracy of  $\pm 0.04$  liter  $\text{min}^{-1}$  ( $Vo_2$  liter  $\text{min}^{-1}$ ) ("Astrand and Rodahl, 1977, 293). Oxygen consumption is measured using a Douglas Bag or a portable respirometer which collects expired air during exercise or work over a specific period of time. The amount of air in the respirometer is measured and a typical recording of oxygen consumption may be seen in Figure 2.1.

The oxygen consumption increases during the first two minutes of exercise to a steady state (in this case  $2.5 \text{ litres min}^{-1}$ )

where oxygen consumption is equal to the demand for oxygen by the body tissues.

Figure 2:1 Oxygen Consumption During Work.



Source: Astrand and Rodahl, 1977, P. 296.

At the termination of the exercise, the oxygen consumption gradually decreases, returning to its resting level (in this case  $0.25 \text{ litres min}^{-1}$ ). The oxygen debt is described as the total oxygen consumption minus the resting oxygen consumption (Astrand and Rodahl, 1977, 313) and is always present after exercise. Part of the oxygen debt may be alactacid, in that it is not involved with lactic acid, or lactacid where it is involved due to a build up of lactic acid in body tissues (which will be explained when anaerobic processes are referred to).

The length of time for oxygen consumption to increase to 2.5 litres per minute in Figure 2:1 is due to the sluggish adjustment of respiration and circulation (the oxygen transporting systems) to the pace of the exercise. The steady state (2.5 litres min<sup>-1</sup> in Figure 2:1) corresponds to a work situation where the oxygen consumption is equal to the demand for oxygen by the body tissues so there is no lactic acid accumulation.

In many types of muscular work/exercise, the oxygen consumption is linearly positively related to work load. In other words an increase in work load will result in a corresponding increase in oxygen consumption. The maximal oxygen consumption (maximal aerobic power) is the highest oxygen consumption attainable during physical work while breathing air at sea level. The work time is between two and six minutes, depending on the work load.

## 2.2 Anaerobic Processes

"During light work, the required energy may be produced almost exclusively by aerobic processes . . . , but during more severe work, anaerobic processes are brought into play as well.

Anaerobic energy - yielding metabolic processes play an increasingly greater role as the severity of the work load increases"

(Astrand and Rodahl, 1977, 308).

When the individual is performing at a level where his metabolic processes are anaerobic then there is a deficit of oxygen to the muscles and resulting production of lactic acid in the blood to

the muscles. Astrand and Rodahl (1977) outline the oxygen deficit and lactic acid production as follows:

1. During light exercise, the oxygen store in the muscle plus the oxygen supplied as the respiration and the circulation adapt to the work will completely cover the oxygen need. Most of the ordinary daily occupations belong to this category of work.
2. During exercise of moderate intensity, anaerobic processes contribute to the energy output at the beginning of the exercise until the aerobic oxidation can take over and completely cover the energy demand. Any produced lactic acid diffuses into the blood and can be traced in the venous blood draining the muscle and, eventually, the arterial blood if the quantity of lactic acid produced is high enough. As the work proceeds, the blood lactate concentration falls again to the resting level and the work can be continued for hours (Bang, 1936).
3. During heavier exercise, the lactic acid production and, therefore, the rise in blood lactate concentration are higher and remain high throughout the work period. The length of time which the work load will be endured will, to some extent, depend on the subject's motivation.

4. During very severe exercise, there is a continuously growing oxygen deficit and an increase in the lactate content of the blood because of the predominantly anaerobic metabolism. The work cannot be continued for more than a few minutes, as a rule, because the subject's muscles can no longer function (Astrand and Rodahl, 1977, 308).

Generally at the commencement of work and during heavy work there is a discrepancy between the demand and availability of energy by aerobic processes. Because of this the energy must be contributed anaerobically which results in the production in the body of lactic acid. The heavier the work compared to the individual's maximum aerobic power, the larger is the oxygen deficit and the more important is the anaerobic energy yield.

### 2.3 Measuring the Cost of Work

The physical cost of work may be assessed either by measuring the oxygen consumption ( $\text{Vo}_2$ ) during the work itself or by indirectly estimating the oxygen consumption from the heart rate (pulse) recorded during the work. This indirect calorimetry (Passmore and Durnin, 1955) has been an established method of measuring the energy cost of many activities for some time now.



## 2.4 Oxygen Consumption, $Vo_2$

Traditionally, the Douglas Bag has been used to collect expired air in laboratory settings but because of its bulk it is inappropriate for use in field settings. However highly portable respirometers have been developed which allow for the collection of expired air under field conditions. Also very quick methods of analysing the oxygen and carbon dioxide content of the air samples have been developed. Oxygen consumption ( $Vo_2$ ) is expressed either as:

- (a) Litres per minute ( $L \text{ min}^{-1}$ ), or
- (b) Cubic centimetres per minute per kilogram of body weight ( $cm^3 \text{ kg}^{-1} \text{ min}^{-1}$ ).

However oxygen consumption expressed either as (a) or (b) does not explain the cost of work completely unless it is expressed as a percentage of maximum oxygen consumption ( $Vo_{2 \text{ max}}$ ).

Maximum oxygen consumption can be determined by direct measurement of the individual performing the work, but this is not necessary. However it may also be estimated on the basis of data obtained from submaximal tests or from regressions of data from the variables which influence maximum oxygen consumption. Dehn and Bruce (1972) (in Roozbazar et al, 1979) present a formula for estimating maximum oxygen consumption that is related to age and weight, where:

$$\text{Vo}_2 \text{ max} = 56.592 - 0.389 A$$

Where  $\text{Vo}_2 \text{ max}$  = maximum oxygen consumption ( $\text{cm kg}^{-1} \text{ min}^{-1}$ ),  
and

A = age in years .

This is one of the equations under study in this research report and will be elaborated in the final section of the chapter where the section of the Roozbazer et al (1979) model is presented.

Shephard et al (1976) present an equation for estimating maximum oxygen consumption which is more complex than the above, where:

$$\text{Vo}_2 \text{ max} = 42.5 + 16.6 (\text{Vo}_2) - 0.12 (W) - 0.12 (H) - 0.24 (A).$$

Where  $\text{Vo}_2$  = oxygen cost in litres per minute on a step test,

W = body weight in kilograms,

H = recovery heart rate in beats per minute, and

A = age in years.

Maximum oxygen consumption ( $\text{Vo}_2 \text{ max}$ ) increases with age.

Beyond twenty years it declines gradually

(Astrand and Rodahl, 1977). One of the factors in the decline of maximum oxygen consumption beyond twenty years of age is seen as the decrease in the maximal heart rate, which lessens the functional range of the oxygen transporting system.

The percentage of maximum oxygen consumption that is the maximum work load that should not be exceeded in order to avoid injury or possibly even death is 50% of  $\text{Vo}_2 \text{ max}$ . Within the above maximum an Acceptance Work Load (AWL) can be expressed as that level of physical activity which can be sustained by an individual in an eight hour working day in a physiologically steady state

and which will not cause fatigue or discomfort (Saha et al, 1979). An alternative term for Acceptable Work Load, possibly in more general use, is Relative Load (RL) which is the percentage of maximum oxygen consumption spent while performing a task (Saha et al, 1979). Another term is Endurance Limit (Muller, 1953). The concept of relative load has been researched and found to be of importance in those occupations which involve heavy muscular work (Caplan and Lindsay, 1946; Mackworth, 1950; Saha et al, 1979), and manual labour where the environmental temperature is high (Saha, 1978).

Lehmann et al (1950) assumed that the Acceptable Work Load (AWL) should not exceed 20% RL (Saha et al, 1979). However it is felt that this has been incorrectly stated in Saha et al's (1979) article. If Acceptable Work Load (AWL) is synonymous with Relative Load (RL) then one cannot be expressed as a percentage of the other. Also the Acceptable Work Load which results from this as a percentage of maximum oxygen consumption is extremely low. For example, if  $RL = 50\% \text{ } \dot{V}O_2 \text{ max}$ , then  $AWL = 20\% (50\% \dot{V}O_2 \text{ max}) = 10\% \dot{V}O_2 \text{ max}$ . In plain language, if Relative Load is 50% of maximum oxygen consumption, and if the Acceptable Work Load is equal to or less than 20% of Relative Load, then the Acceptable Work Load is less than or equal to 20% of 50% of maximum oxygen consumption. It is felt that this was not what was intended by Saha et al (1979), but that the Acceptable Work Load (AWL) should not exceed 20% of maximum oxygen consumption ( $\dot{V}O_2 \text{ max}$ ). Later research findings recommended that the Relative Load should be 33% of the individual's maximum oxygen consumption (Lehmann, 1962; Michael et al, 1961; Bink, 1962; Saha, 1969; Bonjer, 1968). A limit of 50% of maximum oxygen

consumption as Relative Load or Acceptable Work Load was postulated (Astrand and Rhming, 1954-55; P.O. Astrand, 1956, 1960; I. Astrand, 1960; Morris and Chevalier, 1961; Whyndham et al, 1963; Christenson, 1963) but this 50% limit was considered to be too high for a steady state if the work lasts for the whole day (Astrand and Rodahl, 1977). Workers have been found to exert about 40% of maximum oxygen consumption if left to themselves and this has been considered to be a reasonable limit of Relative Load (Astrand, 1967). So an Acceptable Workload, or Relative Load, would be between 33% and 40% of maximum oxygen consumption (Saha, et al, 1979).

Fordham et al (1978) attempted to find the cost of work in medical nursing and used the calculation

$$\frac{\text{Vo}_2 \text{ at work}}{\text{Vo}_2 \text{ max predicted}} \times 100$$

to estimate the average relative oxygen consumption. Oxygen consumption at work was measured using the Miser Respirometer and the oxygen content of the expired air samples was analysed using a modified paramagnetic analyser. "Predicted maximum oxygen consumption was calculated by extrapolation of the regression line of oxygen consumption on heart rate to the predicted maximum heart rate" (p. 334). They found that the average relative work load (of nursing) was well within the 30% recommended limit (Bonjer, 1968).

Goldsmith et al (1978) attempted to find the cost of work on a vehicle assembly line and used the same calculations to be

found in Fordham et al (1978), above, to estimate the average relative oxygen uptake. Measurement of oxygen consumption at work and predicted maximum oxygen consumption was also identical to that in the Fordham et al (1978) study. Goldsmith et al (1978) classified work on a vehicle assembly line as light industrial work in that the average relative work load of their subjects ranged from 18% - 33%, the mean being 24% ( $\pm 4.3\%$ ). Only two of their subjects exceeded 30% relative work load.

Oxygen consumption has been measured using analysis of expired air collected in a Gasometer or Douglas Bag while subjects have been walking and running on a road surface (Soule et al, 1978; Bergh et al, 1976), a treadmill (Saha et al, 1979; Davies and Thompson, 1979; Bergh et al, 1976), and riding a bicycle ergometer (Saha, 1978; Bergh et al, 1976). However, it has been shown (Bergh et al, 1976) that estimates of maximum oxygen consumption will differ depending on which activity is performed while measurement of oxygen consumption takes place. These differences are:

- (a) Oxygen consumption in maximal armwork is lower than in maximal leg work.
- (b) For most subjects, oxygen consumption during maximal uphill running is higher than in maximal cycling.

- (c) But when comparing combined arm and leg exercise to leg bicycling, a 5-10% higher maximum oxygen consumption was found during combined arm and leg exercises. Bergh et al (1976) report that others have found maximum oxygen consumption to be the same in these two types of exercises and that the discrepancy in these results is able to be explained by the amount of armwork relative to the total work which varied from 20% - 35%.

Once the subject's oxygen consumption has been measured it can be compared to the subject's maximum oxygen consumption to ascertain the "cost" of the activity and this comparison will also indicate whether or not the subject is working within the limits of Relative Load.

## 2.5 Heart Rate (HR)

The rate of oxygen consumption ( $Vo_2$ ) to measure energy expenditure is widely used but is considered by some researchers (Leblanc, 1957; Durnin and Edwards, 1955; Muller, 1953) to be too intricate and time consuming and to have little advantage over mere measurement of ventilation as a predictor of energy expenditure. Other researchers (Brouha, Smith De Lanne and Maxfield, 1961; Brouha and Maxfield, 1962; Brouha, Maxfield, Smith and Stopps, 1963) report that oxygen consumption is not a reliable indicator of strain induced by a warm working environment.

All these researchers have shown that the use of exercise and recovery pulse rate reflect energy expenditure or strain more satisfactorily than oxygen consumption.

Heart rate is expressed in beats per minute. The Maximum Heart Rate (HR max) achieved in maximal work or exercise for an individual has a linear relation to the age of that individual and may be expressed in the following equation from Bar-Or and Buskirk (1974) which forms part of the section of the Roozbazar et al (1979) model which is the central concern of the present research:

$$\text{H.R. Max} = 209.2 - 0.74 A$$

Where HR max = maximum heart rate in beats per minute

$$(\text{HR max b min}^{-1})$$

And A = Age in years

As with maximum oxygen consumption, maximum heart rate also decreases with age. However maximum heart rate has a higher negative correlation with age than does maximum oxygen consumption (Roozbazar et al, 1979).

Astrand and Rodahl (1977) present a simple formula for the target heart rate for the termination of submaximal exercise testings, as the target rate will be close to the subjects' maximum heart rates. It is:

$$\text{Target H.R.} = 220 - A$$

Where A = age in years.

"The basis for this target heart rate is the fact that the maximal heart rate declines with age and that mean values are in the order of 220 minus the subject's age in years. Considering the wide scatter in maximal heart rates reported in the literature it is quite meaningless to be too sophisticated in the choice of the target heart rate. the Scandinavian norms are quite simple to remember, and they have passed the test of time. At present there is hardly any better alternative available for the choice of a submaximal end point. (An analysis of the blood lactate concentration after the end of the exercise will give a hint of whether the subject was working close to his or her maximum or not, that is whether or not the anaerobic energy yield was significant). (Astrand and Rodahl, 1977, 354).

Goldsmith et al (1978) estimated maximum heart rate based on electrocardiograph readings during the last two minutes of work, as well as measuring oxygen consumption and minute ventilation with a Douglas Bag. (Minute ventilation is the mass movement of gas in and out of the lungs. More precisely, it is the volume of air exhaled per minute, because the amount of air inhaled is usually greater than the amount exhaled. However the value of minute ventilation is dependent upon a knowledge of oxygen consumption).

"Regression lines of oxygen consumption and heart rate were calculated for each individual and extrapolated to the predicted maximum heart rate" (Goldsmith et al, 1978, 317). The researchers found that, "the levels of heart rates during work . . . . .



indicated that work was of a moderate intensity, but the results suggest that for about 15% of the workers the work load could be classified as heavy. "The increment in heart rates above resting levels are higher than those described by Brouha (1960) for optimal work" (Goldsmith et al, 1978, 322). However Goldsmith et al (1978) used sleeping heart rates as a base instead of resting heart rates at work so the increment is bound to be higher than it should be.

Fordham et al (1978) calculated maximum heart rate in an identical manner to Goldsmith et al (1978). They found that nursing was in the category of light industrial work. They found that the mean heart rates for all their subjects were lower than the recommended maximum levels for eight hours of work. Further, they found that the levels for heart rate of the nurses were comparable with those of housewives with young children and of university students.

Leblanc (1957) found that when subjects walked a distance of one mile at speeds of between 3.1 and 4.5 miles per hour, a plateau of heart rate was soon reached as the demand for increased blood flow was satisfied by the heart. When the exercise ceased there was a rapid return to the pre-exercise pulse rate. When the subjects ran one mile at speeds of between 5.1 and 9.5 miles per hour their pulse rates continued to increase and there was a delayed return to the pre-exercise pulse rate level.

Leblanc's (1957) subjects then ran at 5.5 miles per hour over distances varying from one quarter of a mile to two and one half miles.

It was found that the greater the distance run, the greater the increase in pulse rate and the longer the time for its return to pre-exercise levels. Leblanc (1957) concluded that the work and recovery pulse rates reflect the intensity and the duration of the exercise.

Maxfield and Brouha (1963) refer to the Cardiac Cost of exercise or work and describe it as the measurement of the area under the curve obtained by plotting heart rate per minute for each minute during work and recovery.

So: (a) Total Cardiac Cost above Zero = Cardiac Work Cost +  
Cardiac Recovery Cost.

Where Cardiac Work Cost = heart rate during work, and  
Cardiac Recovery Cost = heart rate during recovery.

(b) Total Cardiac Cost above resting level  
= Total Cardiac Cost above Zero - Cardiac Rest Cost

Where Cardiac Rest Cost = Average resting heart rate x minutes  
of work and recovery.

Total Cardiac Cost is seen to have advantages over steady state or maximal heart rates in that it takes into account the duration of the working time and any cardiac "debt" which may have been incurred while working and which is repaid during recovery. In explaining their preference for total cost above zero rather than total cost above resting, the authors conclude that the total cost above zero measures all the strain experienced by the subject and eliminates the difficulties present in determining the "true" resting heart rate.

## 2.6 Oxygen Consumption ( $\text{Vo}_2$ ) and heart Rate Heart Rate (HR)

While researchers cited in the previous sections, above, have used one method to measure the effects of work, there are some for whom the use of a single instrument to measure the loads on individuals is inappropriate, for example Davis et al (1969) and Goldsmith et al (1978). Both research studies cited above measured heart rate using continuous E.C.G., Goldsmith et al (1978) measured oxygen consumption and minute ventilation using a Douglas Bag while Davis et al (1969) measured minute ventilation only from which they calculated measures of oxygen consumption. Goldsmith et al (1978) arrived at Average Relative Work Loads, discussed previously, and found that their subjects' ARWL's ranged from 18% to 33%. These authors had used regressions of oxygen consumption on heart rate for each subject, extrapolated these to the predicted maximum heart rate to obtain maximum oxygen consumption.

Davis et al (1969) considered that it was wise to measure both heart rate and oxygen consumption, since oxygen consumption alone could not show changes in temperature and humidity in the work environment and they considered that any decreased operator capacity would be lost if heart rate were omitted.

## 2.7 The Model Under Study

In 1979 Roozbazar, Bosker and Richerson (1979) developed a theoretical model to estimate some ergonomic parameters from age, height and weight. While their model predicted anthropometric, biochemical and work physiology parameters this research is concerned only with the section of the model predicting work physiology parameters of oxygen consumption and heart rate from age and weight.

The following description of the section of the model under investigation is taken from Roozbazr et al (1979), pp 50-51.

"Maximum oxygen consumption is the most accepted index of physical fitness. It is a characteristic that is mostly independent of emotional and environmental variables. It is affected by age, the degree of training, sex, altitude, and a few other variables. The following equation developed by Dehn and Bruce (1972) relates the age with the maximum oxygen consumption. It is obtained from 17 studies covering about 700 observations.

$$\text{Vo}_2 \text{ max} = 56.592 - 0.398A \text{ (I)}$$

Where  $\text{Vo}_2 \text{ max}$  = maximum oxygen consumption  
 $\text{cm}^3 \text{ kg}^{-1} \text{ min}^{-1}$ .

A = age, y.

Maximal heart rate achieved in maximal work or exercise for a given individual is linearly related to age. The following equation is obtained from the literature for 1931 men and women (Bar-or and Buskirk, 1974):

$$\text{HR max} = 209.2 - 0.74 A \quad (\text{II})$$

Where HR max = maximum heart rate, beats min<sup>-1</sup>.

$$A = \text{Age, y.} \quad (\text{Roozbazaretal, 1979})$$

### Objective

The objective of this report is to check the validity of this approach in the laboratory against a standard of direct measurement.

The values of  $\text{Vo}_2$  max and HR max in equations (I) and (II) can be compared with values obtained in the laboratory using submaximal test, in order to test the validity of equations (I) and (II).

Similarly equation:

$$\text{HR} = 56.02 + 66.84 \text{ Vo}_2 - 8.4 \text{ Vo}_2^2 \quad (\text{III})$$

From Roozbazar et al's (1979) model can be tested using HR values predicted by Roozbazar et al (1979) as compared with those obtained by direct measurement.

Finally, a further check on the Roozbazar et al (1979) values of  $Vo_2$  max can be made, using equation (III), by substituting in III the suggested value of  $0.35 Vo_2$  max as obtained from the Roozbazar et al (1979) equation (I) and the experiment.

## CHAPTER 3

### Description of the Experiment

Because the intention of this research was to validate the equations proposed in the Roozbazar et al (1979) research, it was necessary that data be collected from subjects participating in tests of submaximal aerobic power. Generally three methods of producing standard work loads have been applied in laboratory settings: running on a treadmill, working on a bicycle ergometer and using a step test. The major criteria of choice of these three methods are: the work should involve large muscle groups; and the measurement of the oxygen consumption should be started when the work has lasted a few minutes, to allow the oxygen consumption to reach its maximum. Preferably several submaximal work tests should be performed in experiments extended over several days. Ideally, a definite plateau should be reached when relating oxygen consumption to work load (Astrand and Rodahl, 1977, 334).

#### 3.1 Choice of Test Equipment

There is, however, some disagreement about whether the three types of work - treadmill running, ergometer cycling or step test - give the same maximal oxygen consumption. some studies (see Table 3:1) state that maximum oxygen consumption values for treadmill running (uphill and horizontal) are on average 5 to 8 percent higher than for cycling, and about 3 percent higher than the step test. An explanation for this disparity is not readily available at present : there should be no difference between maximal oxygen consumption when running uphill or riding a bicycle ergometer, nor should there be a difference between maximum oxygen consumption on uphill running and the step test.

In this research the chosen instrument upon which to measure the cost of work was a Repco Cycle Ergometer. An ergometer was preferred for the submaximal tests to be carried out for a variety of reasons. It was less expensive than a treadmill (but much more so than a step), portable and needed no electricity.

TABLE 3:1

Mean values for maximal oxygen uptake attained in various types of exercise, compiled from the literature. Maximal oxygen uptake recorded during uphill running is termed 100 percent.

| Type of exercise                                        | $\dot{V}_{O_2}$ max, in percent | Some pertinent references                                                                                                                           |
|---------------------------------------------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Running, uphill ( $\geq 3^\circ$ incline)               | 100                             | Chap. 9; Hermansen, Ekblom, and Saltin, 1970; Hermansen and Saltin, 1969; Kamon and Pandolf, 1972                                                   |
| Running, horizontal                                     | 95-100                          | Hermansen and Saltin, 1969; Kasch et al., 1976                                                                                                      |
| Bicycling, upright (60 rpm)                             | 92-96                           | Chap. 9; Glassford et al., 1965; Hermansen, Ekblom, and Saltin, 1970; Hermansen and Saltin, 1969; Kamon and Pandolf, 1972; McKay and Banister, 1976 |
| Bicycling, supine                                       | 82-85                           | Chap. 9                                                                                                                                             |
| Bicycling, upright, one leg                             | 65-70                           | Davies and Sargent, 1974                                                                                                                            |
| Arm cranking                                            | 65-75                           | Chap. 9                                                                                                                                             |
| Arm and leg (with 10-20% of the total load on the arms) | 100                             | Chap. 9                                                                                                                                             |
| Step test                                               | 97                              | Kasch et al., 1966; Shepard et al., 1968                                                                                                            |

Source: Astrand and Rodahl. 1977. Page 335.



Most important, the chest remains quite immobile which allows electrodes for heart rate monitors to register good soundings. Also, according to Astrand and Rodahl (1977), the energy output or oxygen consumption can be predicted with greater accuracy than for any other type of exercise. Within limits, the mechanical efficiency is independant of body weight, which may be an advantage in studies which require repeated examinations over the years, but the work load can be selected simply according to the subjects gross body weight (for example, 1 or 2 watts per kilogram) (p. 337)

### 3.2 Experimental Trials

The duration of a trial on the ergometer was six minutes. The load for each trial was set at two watts per kilogram of subjects' body weight, the subjects being weighed before each trial. The intention was that each subject's heart rate should be at least 140 beats per minute for subjects under fifty years of age.

The trials were carried out for each subject at the same time of day to avoid variations in diurnal rhythms. For example, Subject 1 always performed at approximately 3.30 pm, Subject 3 at 3.00 pm and Subject 7 at 2.30 pm. Also subjects participated in trials not less than: one hour following a light meal; three hours following a heavy meal, and one hour following cigarette smoking.

### 3.3 The Subjects

The subjects for the experiment were seven adult caucasian males, ranging in age from thrity two years to forty nine years. Their particulars are shown in table 3:2.

Table 3:2 Experimental Subjects Age and Weight

| <u>Subject</u> | <u>Age</u> | <u>Weight</u> |
|----------------|------------|---------------|
| 1              | 49         | 95 kg         |
| 2              | 35         | 76 kg         |
| 3              | 45         | 85 kg         |
| 4              | 34         | 82 kg         |
| 5              | 40         | 57 kg         |
| 6              | 32         | 85 kg         |
| 7              | 34         | 85 kg         |

It had originally been intended to use ten subjects to complete four trials each on the ergometer, giving a total of forty sets of Heart Rate and Oxygen consumption figures. However time constraints at the end of the academic year meant that only seven subjects were able to participate. Subjects 2 and 3 each completed five trials while Subjects 1, 4, 5, 6 and 7 each completed six trials, giving a total of forty trials.

### 3.4 Method

3.4.1 Each subject's particulars were noted, i.e. age and weight.

3.4.2 Maximum Oxygen Consumption and Maximum heart rate were calculated from the equations presented in the Roobazar et al (1979) model.

$$V_{O_2} \text{ max} = 56.592 - 0.398 A \text{ (Dehn \& Bruce).}$$

$$HR \text{ max} = 209.2 - 0.74 A \text{ (Bar-Or \& Buskirk).}$$

Maximum Heart Rate was also calculated using Astrand & Rodahl's (1977) equation based on Scandinavian data.

$$HR \text{ max} = 220 - A \text{ (Astrand and Rodahl).}$$

This information is presented in Table 3:3. The formulae used to arrive at the predicted litres of oxygen consumed and heart rate per minute are shown, using Subject 1 as an example.

Table 3:2  $\text{Vo}_2$  max and HR max values calculated from equations by Dehn and Bruce, Bar-Or and Buskirk, and Astrand and Rodahl

| i | Ay | Wkg | D & B ( $\text{l min}^{-1}$ ) | B-O & B ( $\text{b min}^{-1}$ ) | A & R ( $\text{b min}^{-1}$ ) |
|---|----|-----|-------------------------------|---------------------------------|-------------------------------|
| 1 | 49 | 95  | 3.52                          | 173                             | 171                           |
| 2 | 35 | 76  | 3.24                          | 183                             | 185                           |
| 3 | 45 | 85  | 3.29                          | 176                             | 175                           |
| 4 | 34 | 82  | 3.53                          | 184                             | 186                           |
| 5 | 40 | 57  | 2.32                          | 180                             | 180                           |
| 6 | 32 | 85  | 3.73                          | 185                             | 188                           |
| 7 | 34 | 85  | 3.66                          | 184                             | 186                           |

Key: i = Subject  
 Ay = Age in Years  
 Wkg = Weight in Kilograms  
 D & B = Dehn and Bruce  
 $\text{l min}^{-1}$  = Litres of oxygen consumed per minute.  
 B-O+B = Bar-Or and Buskirk  
 $\text{b min}^{-1}$  = Heart beats per minute  
 A & R = Astrand and Rodahl

Subject 1, as can be seen from Table 3:2, was 49 years of age and weighed 95 kilograms. So for Equation I (Dehn and Bruce) the Subject's predicted maximum oxygen consumption was as follows:

$$\begin{aligned}
 \text{Vo}_2 \text{ max} &= 56.592 - 0.398A \\
 &= 56.592 - 0.398 (49) \\
 &= 56.592 - 19.502 \\
 &= 37.09 \text{ cm}^3 \text{ kg}^{-1} \text{ min}^{-1} \\
 &= 37.09 \text{ cm}^3 \text{ min}^{-1} \times 95 \text{ kg} \\
 &= 3523.55 \text{ cm}^3 \text{ min}^{-1} \\
 &= 3.52 \text{ l min}^{-1}
 \end{aligned}$$

Where: A = age in years  
 $\text{cm}^3 \text{ kg}^{-1} \text{ min}^{-1}$  = cubic centimetres of oxygen per kilogram of bodyweight per minute.  
 $\text{cm}^3 \text{ min}^{-1}$  = cubic centimetres of oxygen per minute.  
 $\text{l min}^{-1}$  = litres of oxygen per minute.

For Equation II (Bar-Or and Buskirk)

$$\begin{aligned} \text{HR}_{\text{max}} &= 209.2 - 0.74A & (\text{II}) \\ &= 209.2 - 0.74(49) \\ &= 209.2 - 36.26 \\ &= 172.94 \\ &= 173 \text{ beats min}^{-1} \end{aligned}$$

Where:  $A$  = Age in years  
Beats  $\text{Min}^{-1}$  = Heart beats per minute.

For Astrand and Rodahl's equation,

$$\begin{aligned} \text{HR}_{\text{max}} &= 220 - A & (\text{Astrand and Rodahl}) \\ &= 220 - 49 \\ &= 171 \text{ beats min}^{-1} \end{aligned}$$

Where  $A$  = Age in years  
Beats  $\text{Min}^{-1}$  = Heart beats per minute.

The use of the Astrand and Rodahl (1977) equation was made as a comparison measure. As can be seen from Table 3:2 and the above formulae for Subject 1, this simple equation yields a predicted maximum heart rate that is of roughly comparable value to the Bar-Or and Buskirk equation for predicting maximum heart rate.

#### 3.4.3.

Each subject then completed his series of trials. Following each trial (the subjects' maximum oxygen consumption was predicted from Astrand's (1960) standardised data for use with the ergometer. Again the use of predicted  $\text{Vo}_2$  max from Astrand (1960) was made as a comparison measure. Using Astrand's (1960) data maximum oxygen consumption was predicted from actual heart rate in each trial. For Subject 1, trial 1, actual heart rate was 124 beats per minute at 150 watts load. The 150 watts load was selected for this subject initially because of his age (49) and possible level of unfitness: although the subject had been a keen rugby player as a young man he had not actively participated in serious sport for about twenty years. The experimenter felt that the load for the first trial should not be excessive in case injury or heart problems resulted from it. For subject 1, age 49, weight 95kg, heart rate 124 beats per minute predicted  $\text{Vo}_2$  max was as follows:

$$\begin{aligned}\text{Vo}_2 \text{ max at } 124 \text{ b min}^{-1} &= 36 \text{ ml kg}^{-1} \text{ min}^{-1} \\ &= 36 \text{ ml min}^{-1} \times 95 \\ &= 3420 \text{ ml min}^{-1} = 3.420 \text{ l min}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Where } \text{b min}^{-1} &= \text{heart beats per minute} \\ \text{ml kg}^{-1} \text{ min}^{-1} &= \text{millilitres of oxygen per kilogram per minute.} \\ \text{l min}^{-1} &= \text{litres of oxygen per minute.}\end{aligned}$$

However on trials two to six the load was set at 200 watts and predicted  $\text{Vo}_2$  max with a heart rate of 140 beats per minute for trial two became:

$$\begin{aligned}\text{Vo}_2 \text{ max at } 140 \text{ b min}^{-1} &= 38 \text{ ml kg}^{-1} \text{ min}^{-1} \\ &= 38 \text{ ml min}^{-1} \times 95 \\ &= 3610 \text{ ml min}^{-1} \\ &= 3.61 \text{ l min}^{-1}\end{aligned}$$

$$\begin{aligned}\text{Where } \text{b min}^{-1} &= \text{heart beats per minute} \\ \text{ml kg}^{-1} \text{ min}^{-1} &= \text{millilitres of oxygen per kilogram of body weight per minute.} \\ \text{l min}^{-1} &= \text{litres of oxygen per minute.}\end{aligned}$$

Predicted  $\text{Vo}_2$  max using the Astrand (1960) formula are presented for all subjects in all trials in Table 3:4, where a comparison may be made with predicted  $\text{Vo}_2$  max from the Dehn and Bruce equation,  $\text{Vo}_2 \text{ max} = 56.592 - 0.398A$ . It may be seen from Table 3:4 that differences exist between the values calculated from age and weight (Dehn and Bruce) and values calculated from actual heart rate, age, weight and work load. Why such differences exist will not be explored here but such a discrepancy could well form the basis for further research. It is interesting to note however that when the HR max values from Dehn and Bruce, and Astrand and Rodahl, in Table 3:2 are compared the difference between values is not as obvious as that in Table 3:4.

Table 3:4 Predicted  $\text{Vo}_2$  max from the Dehn and Bruce equation and Astrand's standardised data.

| i | $\text{Vo}_2$ max D & B | $\text{Vo}_2$ max, Astrand<br>Trials |     |     |     |     |     |
|---|-------------------------|--------------------------------------|-----|-----|-----|-----|-----|
|   |                         | 1                                    | 2   | 3   | 4   | 5   | 6   |
| 1 | 3.52                    | 3.4                                  | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 |
| 2 | 3.24                    | 2.8                                  | 2.9 | 2.9 | 2.8 | 2.9 | -   |
| 3 | 3.29                    | 3.3                                  | 3.9 | 3.9 | 3.6 | 3.8 | -   |
| 4 | 3.53                    | 5                                    | 3.6 | 3.4 | 4.3 | 3.9 | 3.7 |
| 5 | 2.32                    | 3.4                                  | 3.1 | 3.3 | 3.3 | 2.8 | 3.1 |
| 6 | 3.73                    | 3.1                                  | 3.8 | 3.6 | 3.7 | 3.4 | 3.3 |
| 7 | 3.66                    | 4.5                                  | 3.9 | 4.9 | 3.9 | 4.1 | 3.9 |

All figures are in litres of oxygen per minute.

i = subject

D & B = Dehn and Bruce

#### 3.4.4

During each six minute trial the following procedure was followed:

- (a) For the first minute the subject pedaled at a load 50 watts less than that set for each subject. By the end of the first minute each subject attained the set load and continued at this rate for the next five minutes. The rationale for this procedure was to avoid possible strain if each subject began too quickly.
- (b) At the end of three minutes the noseclip was attached to the subject while he maintained the set cycling rate. At three and one half minutes the subject took the rubber mouthpiece of the oxygen gathering apparatus into his mouth and breathed through this. The valve on the apparatus was open so that exhaled air was not collected at this point.

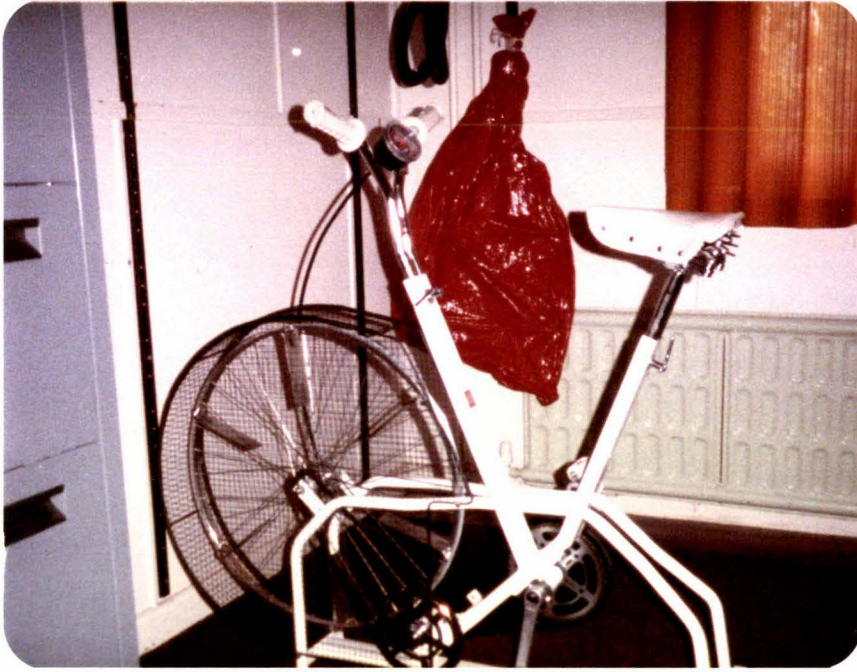
The mouthpiece was not kept in the subjects' mouths for the whole of the six minute trial because it had been noted in pre-trial tests that its presence for the whole six minutes created discomfort and an excess of saliva which was not easily swallowed.

- (c) After four minutes the valve on the oxygen gathering apparatus was closed. Oxygen was then inhaled through the left hand inlet and expired air was exhaled through the right hand outlet to the Douglas Bag. This procedure continued for the next two minutes. The ergometer and oxygen gathering apparatus may be seen in the series of photographs over the page.
- (d) At four minutes, 30 seconds the subject's heart rate was recorded from a Ralita portable heart rate monitor. This monitor produced a constant reading of heart rate per minute so readings were repeated at four minutes, 40 seconds; 4.50; 5 minutes; 5 minutes 30 seconds; 5.40; 5.50 and 6 minutes. The total value of the readings was then divided by the number of readings and the quotient was the average heart rate in the fifth and sixth minutes of the trial.
- (e) At six minutes the trial was halted.
- (f) The volume of expired air collected in a Douglas Bag during the last two minutes of the trial was then measured. This was done by passing the contents of the bag through the gas meter. The gas meter recorded the quantity of expired air in the bag in cubic inches which was then converted into litres. This was done by dividing the quantity, given in cubic inches, by 122.0478. The quotient represents the oxygen consumed in litres per minute.

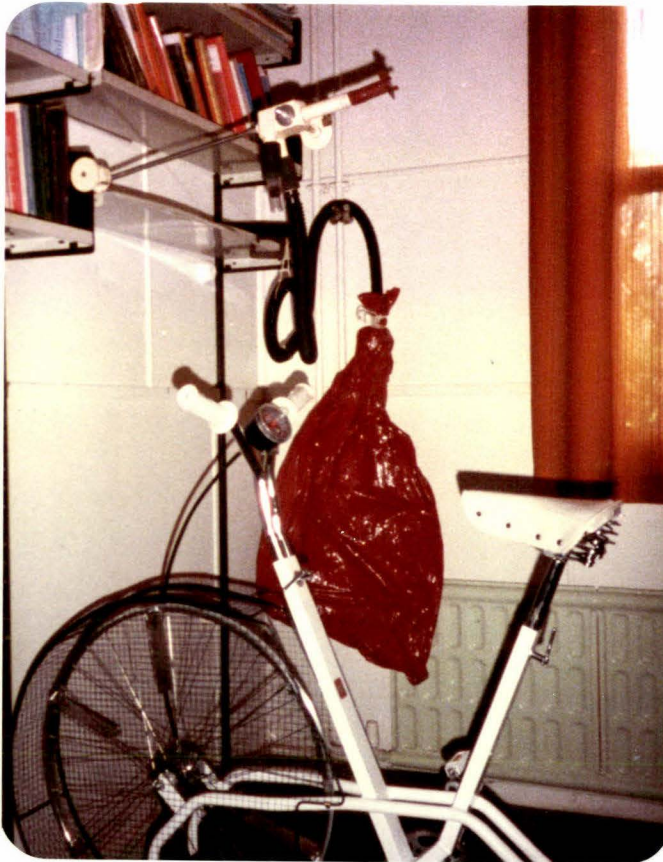
### 3.5 Constraints on The Experiment

The forty trials in the experiment were not completed in a laboratory, but in the experimenter's office. Desks were cleared out of the way and the ergometer was placed in the centre of the space between filing cabinets and the outside wall.



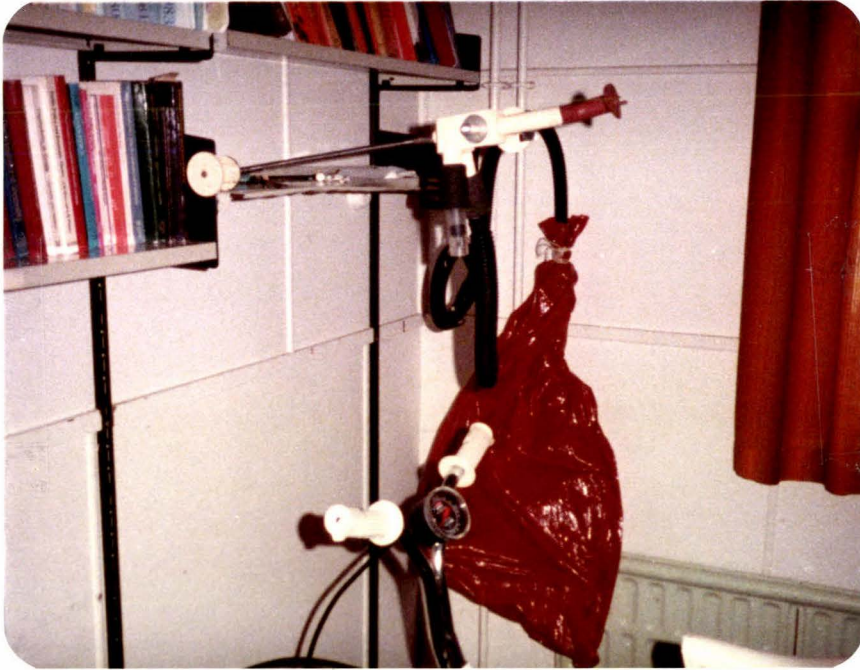


Photograph 1: The Reppo Cycle Ergometer.

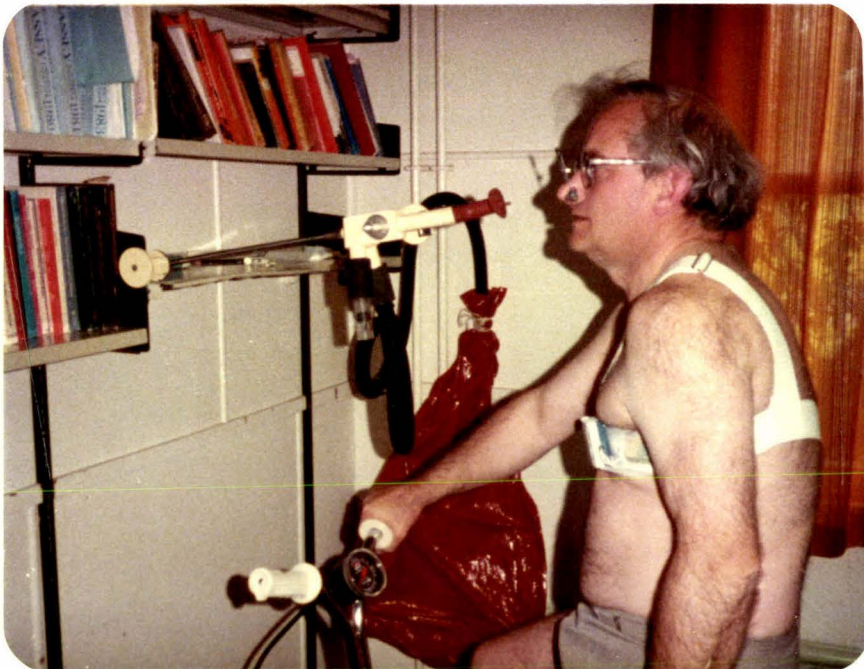


Photograph 2: Ergometer and apparatus for collection of expired air.





Photograph 3: Apparatus for collection of expired air and substitute Douglas Bag.



Photograph 4: Subject about to insert mouthpiece for collection of expired air.

The ergometer was sited facing the wall adjoining this office and the next.

The mouthpiece and valves for oxygen gathering were attached to the bookcase on the wall. A swivel clamp allowed the apparatus to be adjusted to each subject's height when seated on the ergometer. The Douglas Bag which was especially made for this experiment split in a pre-trial test. The Bag was made of thick plastic and the seams were heat-sealed. However one of the seams parted in a pre-trial test and was repaired. Another seam parted during the first experimental trial which resulted in the aborting of that trial and the discarding of the Douglas Bag. A heavy duty garden rubbish bag (plastic) was substituted for the custom-made bag and this became the "Douglas Bag". The rubbish bag (cost about \$0.50) was more reliable than the Douglas Bag (cost about \$60.00), but the use of the rubbish bag may cast doubt upon actual  $\text{Vo}_2$  values.

The gas meter used in the experiment required that the inlet hose to the "Douglas Bag" be disconnected from the mouthpiece and valve apparatus and then inserted manually into the inlet of the gas meter. The bag was then rolled up which forced the expired air in the bag through the meter. Although the greatest care was taken it cannot be guaranteed that none of the expired air escaped during the transfer.

So it may be seen that experimental conditions were not ideal and with the above constraints in mind the results of the experiment will be presented.

# CHAPTER 4

## RESULTS

Actual values for Oxygen Consumption and Heart Rate are presented in Table 4:1.

Table 4:1. Oxygen Consumption and Heart Rate values for seven subjects over the experimental trials.

| Subjects |                 |     |                 |     |                 |     |                 |     |                 |     |                 |     |                 |     |
|----------|-----------------|-----|-----------------|-----|-----------------|-----|-----------------|-----|-----------------|-----|-----------------|-----|-----------------|-----|
| 1        |                 | 2   |                 | 3   |                 | 4   |                 | 5   |                 | 6   |                 | 7   |                 |     |
| A        | 49              | A   | 35              | A   | 45              | A   | 34              | A   | 40              | A   | 32              | A   | 34              |     |
| W        | 95kg            | W   | 76kg            | W   | 85kg            | W   | 82kg            | W   | 57kg            | W   | 85kg            | W   | 85kg            |     |
| Trials   | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  | Vo <sub>2</sub> | HR  |
| 1        | 1.81            | 124 | 2.36            | 148 | 1.5             | 137 | 2.56            | 143 | 1.31            | 131 | 1.91            | 144 | 2.66            | 156 |
| 2        | 2.52            | 140 | 1.94            | 146 | 1.51            | 137 | 2.56            | 154 | 1.96            | 138 | 1.91            | 129 | 2.46            | 148 |
| 3        | 2.76            | 140 | 1.97            | 146 | 1.71            | 138 | 2.59            | 157 | 2.01            | 133 | 1.71            | 139 | 2.39            | 130 |
| 4        | 2.62            | 141 | 2.49            | 176 | 1.76            | 144 | 2.26            | 139 | 2.06            | 133 | 1.72            | 131 | 2.49            | 148 |
| 5        | 2.72            | 143 | 2.03            | 147 | 1.63            | 139 | 2.49            | 148 | 2.01            | 145 | 1.89            | 138 | 1.5             | 144 |
| 6        | 2.57            | 141 | -               | -   | -               | -   | 2.56            | 151 | 2.02            | 139 | 2.15            | 141 | 2.46            | 148 |

Vo<sub>2</sub> in litres per minute.

HR in beats per minute.

Subjects 2 and 3 completed only five trials each, the remainder completed six trials each giving a total number of forty trials.

The above values for Oxygen Consumption and Heart Rate for the subjects in the experimental trials are shown in Figure 4:1. As is evident from the figure, the scatter of the data is not great. At an oxygen consumption of 1.8 litres per minute there are pulse rates of 124 and 144.

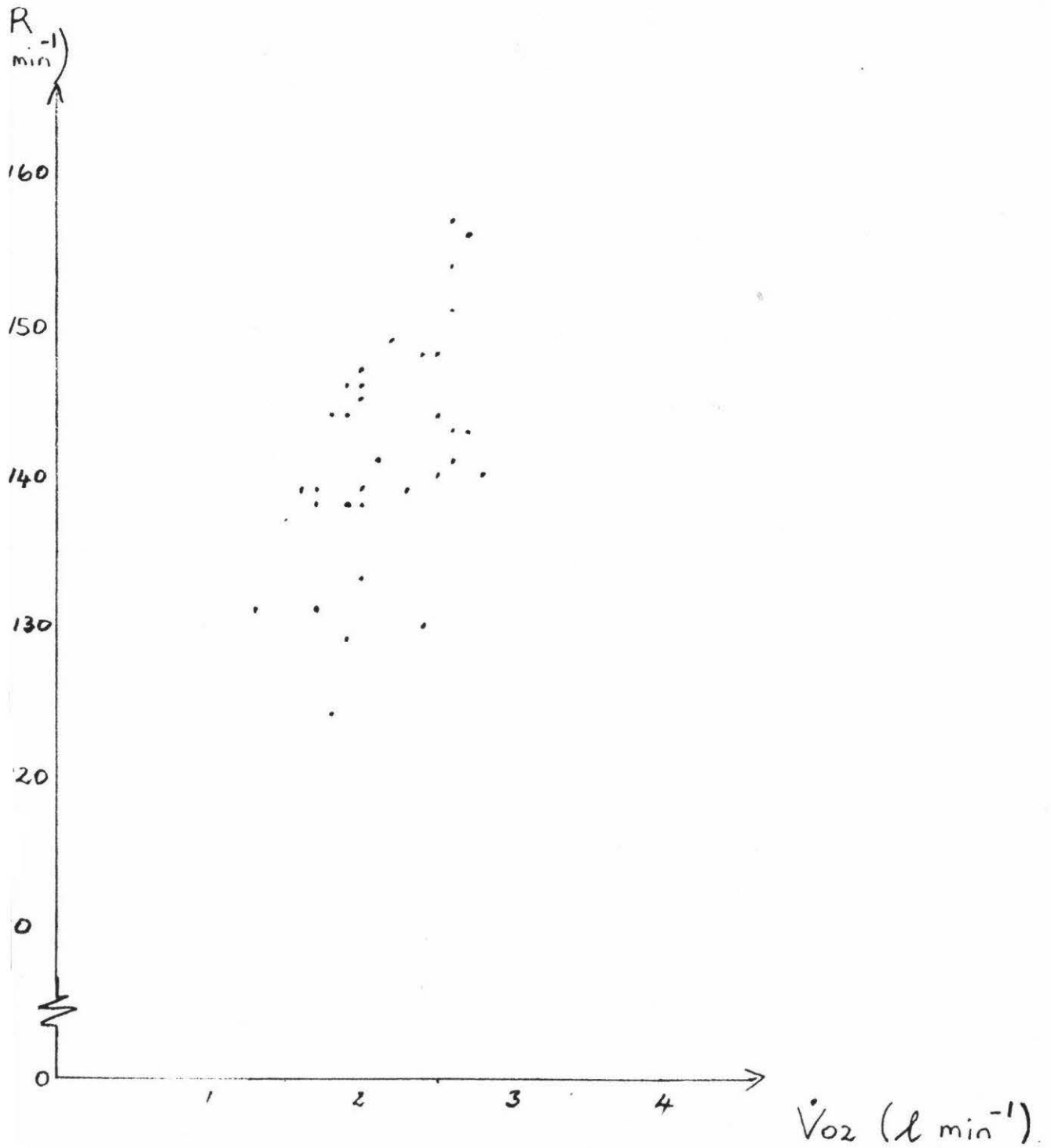


Figure 4:1. Scatter Diagram showing HR (beats  $min^{-1}$ ) Against  $\dot{V}O_2$  Consumption ( $l min^{-1}$ )

A pulse rate of 139 beats per minute represents an oxygen consumption of 1.6 litres per minute for one subject and 2.3 litres per minute for another.

These actual data were used to test the predictive value of the three equations under investigation in this research report, i.e.

$$Vo_{2\max} = 56.592 - 0.398A \text{ (I)}$$

$$HR_{\max} = 209.2 - 0.74A \text{ (II)}$$

$$HR = 56.02 + 66.84 Vo_2 - 8.4 Vo_2^2 \text{ (III)}$$

#### 4.1 Oxygen Consumption ( $Vo_2$ )

In order to test the value of Dehn and Bruce's equation

$$Vo_{2\max} = 56.592 - 0.398 A$$

as a predictor of maximum oxygen consumption, the  $Vo_2$  max for each subject based on the above equation was compared with  $Vo_2$  max values obtained from Astrand's (1969) standard data for work tests with a cycle ergometer. In effect, what was being compared was one predictive measure based on age, with one based on actual heart rate recorded during the last two minutes of each six minute trial.

The data for the comparison in Table 4:2 are the same as those presented in Table 3:3. A t-distribution was used to enable the predictive value of Equation I to be ascertained.

Table 4:2. Values for comparison of Predicted Vo2 max from Equation I and Astrand's standardised data

| i | Vo2max | Vo2max (Astrand) |      |      |      |      |      | $\sum x$ | n | $\bar{x}$ | s    |
|---|--------|------------------|------|------|------|------|------|----------|---|-----------|------|
|   | (I)    | Trials           |      |      |      |      |      |          |   |           |      |
|   |        | 1                | 2    | 3    | 4    | 5    | 6    |          |   |           |      |
| 1 | 3.52   | 3.42             | 3.61 | 3.61 | 3.61 | 3.61 | 3.61 | 21.47    | 6 | 3.58      | 0.08 |
| 2 | 3.24   | 2.81             | 2.89 | 2.89 | 2.81 | 2.89 | -    | 14.29    | 5 | 2.86      | 0.04 |
| 3 | 3.29   | 3.32             | 3.95 | 3.91 | 3.57 | 3.83 | -    | 18.58    | 5 | 3.72      | 0.27 |
| 4 | 3.53   | 5.08             | 3.61 | 3.44 | 4.35 | 3.85 | 3.69 | 24.02    | 6 | 4         | 0.61 |
| 5 | 2.32   | 3.42             | 3.07 | 3.31 | 3.31 | 2.78 | 3.07 | 18.96    | 6 | 3.16      | 0.23 |
| 6 | 3.73   | 3.10             | 3.83 | 3.57 | 3.74 | 3.40 | 3.32 | 20.96    | 6 | 3.49      | 0.27 |
| 7 | 3.66   | 4.51             | 3.91 | 4.91 | 3.91 | 4.08 | 3.91 | 25.23    | 6 | 4.21      | 0.42 |

Key: i = Subject  
 Vo2max(I) = Predicted Vo2max from Equation I  
 Vo2max(Astrand) = Predicted Vo2max from standard data.  
 $\Sigma x$  = Total predicted Vo2max for subjects.  
 n = Number of trials per subject.  
 $\bar{x}$  = Mean value of predicted Vo2 max per subject.  
 s = Standard deviation.

From the data in the above table t scores were obtained for each subject in order to test the hypothesis that Equation I is a reliable predictor of maximum oxygen consumption.

#### Subject 1

$$H: \text{Vo}_2\text{max (I)} = \text{Vo}_2\text{max (Astrand)}$$

$$\alpha = 0.05, df = n-1 = 5, R; t > 2.57$$

$$\text{Let } \text{Vo}_2\text{max (I)} = M, \text{Vo}_2\text{max (Astrand)} = \mu$$

$$t = \frac{M - \mu}{SE}, \quad \text{where } SE = \frac{s}{\sqrt{n}}$$

$$s = 0.08, \quad n = 6,$$

$$\text{So } SE = \frac{0.08}{\sqrt{6}} = 0.033$$

$$t = \frac{3.52 - 3.58}{0.033} = -1.82$$

So if  $R = 2.57$  and  $t = -1.82$  then the hypothesis may be accepted and Equation I is a reliable predictor of maximum oxygen consumption for Subject 1.

### Subject 2

$$H: M = \mu$$

$$\alpha = 0.05, \quad df = 4, \quad R:t > 2.78$$

$$t = \frac{M - \mu}{SE}, \quad \text{where } SE = \frac{s}{\sqrt{n}}$$

$$s = 0.04, \quad n = 5$$

$$\text{So } SE = \frac{0.04}{\sqrt{5}} = 0.02$$

$$t = \frac{3.29 - 2.86}{0.02} = \frac{0.43}{0.02} = 21.5$$

$R = 2.78, \quad t = 17$ , reject the hypothesis for Subject 2.

Subject 3

$$H: M = \mu$$

$$\alpha = 0.05, df = 4, R: t \geq 2.78$$

$$SE = \frac{0.27}{\sqrt{5}} = 0.112$$

$$t = \frac{3.29 - 3.72}{0.112} = \frac{-0.43}{0.112} = -3.8$$

At  $\alpha = 0.05$ , the region of rejection is 2.78 so with  $t = -3.8$  the hypothesis is rejected. However at  $\alpha = 0.01$  the region of rejection is 4.6 and so the hypothesis may be accepted at the 0.01 level.

Subject 4

$$H: M = \mu$$

$$\alpha = 0.05, df = 5, R: t \geq 2.57$$

$$SE = \frac{0.61}{\sqrt{6}} = 0.25$$

$$t = \frac{3.53 - 4}{0.25} = \frac{-0.47}{0.25} = -1.88$$

The hypothesis is accepted : Equation I is a reliable predictor of  $Vo_2$  max for Subject 4.

Subject 5

$$H: M = \mu$$

$$\alpha = 0.05, df = 5, R: t \geq 2.57$$

$$SE = \frac{0.23}{\sqrt{6}} = 0.094$$

$$t = \frac{2.32 - 3.16}{0.094} = \frac{-0.84}{0.094} = -8.9$$

The hypothesis is rejected for Subject 5.



Subject 6

$$H: M = \mu$$

$$\alpha = 0.05, df = 5, R: t \geq 2.57$$

$$SE = \frac{0.27}{\sqrt{6}} = 0.11$$

$$t = \frac{3.73 - 3.49}{0.11} = 0.24 = 2.2$$

The hypothesis is accepted for subject 6.

Subject 7

$$H: M = \mu$$

$$\alpha = 0.05, df = 5, R: t \geq 2.57$$

$$SE = \frac{0.42}{\sqrt{6}} = 0.17$$

$$t = \frac{3.66 - 4.21}{0.17} = \frac{-0.55}{0.17} = -3.24$$

At  $\alpha = 0.05$  the region of rejection is 2.57 so with  $t = -3.24$  the hypothesis is rejected. However at  $\alpha = 0.01$  the region of rejection is 4.03 so the hypothesis may be accepted at the 0.01 level.

A summary of the above information from the seven subjects, in Table 4:3, indicates that Equation I was a reliable indicator of  $Vo_2$  max for Subjects 1, 4 and 6, was adequate for Subjects 3 and 7, but was definitely not for Subjects 2 and 5.

Table 4:3 Summary table of tests of predictive value of  
Equation I for seven subjects.

| i | R    |      | t    | Reject or<br>Accept | (I) is a reliable<br>predictor? |
|---|------|------|------|---------------------|---------------------------------|
|   | 0.05 | 0.01 |      |                     |                                 |
| 1 | 2.57 | 4.03 | 1.82 | accept at 0.05      | Yes                             |
| 2 | 2.78 | 4.6  | 17   | reject              | No                              |
| 3 | 2.78 | 4.6  | 3.8  | accept at 0.01      | Maybe                           |
| 4 | 2.57 | 4.03 | 1.88 | accept at 0.05      | Yes                             |
| 5 | 2.57 | 4.03 | 8.9  | reject              | No                              |
| 6 | 2.57 | 4.03 | 2.2  | accept at 0.05      | Yes                             |
| 7 | 2.57 | 4.03 | 3.24 | accept at 0.01      | Maybe                           |

However as the hypothesis was accepted for five out of seven subjects (71%), Equation I may be seen as a reasonably reliable predictor of Maximum Oxygen Consumption for this sample of adult, white, male subjects.

However in order to confirm this tentative conclusion it was necessary to submit the experimental results to a one way analysis of variance in order to evaluate the homogeneity of the subjects. Statistically the one way analysis of variance was used for testing the hypothesis that the seven subjects in the experiment do not differ significantly with respect to their mean values of oxygen consumption.

Table 4:4 provides summary data from which the one way analysis of variance may be computed.

Table 4:4 Actual values of Vo2 (x) and x<sup>2</sup>

| Trials     | Subject |                |       |                |       |                |       |                |       |                |       |                |       |                |
|------------|---------|----------------|-------|----------------|-------|----------------|-------|----------------|-------|----------------|-------|----------------|-------|----------------|
|            | 1       |                | 2     |                | 3     |                | 4     |                | 5     |                | 6     |                | 7     |                |
|            | x       | x <sup>2</sup> | x     | x <sup>2</sup> | x     | x <sup>2</sup> | x     | x <sup>2</sup> | x     | x <sup>2</sup> | x     | x <sup>2</sup> | x     | x <sup>2</sup> |
| 1          | 1.81    | 3.28           | 2.36  | 5.57           | 1.50  | 2.25           | 2.56  | 6.55           | 1.31  | 1.72           | 1.91  | 3.65           | 2.66  | 7.08           |
| 2          | 2.52    | 6.35           | 1.94  | 3.76           | 1.51  | 2.28           | 2.56  | 6.55           | 1.96  | 3.84           | 1.91  | 3.65           | 2.46  | 6.05           |
| 3          | 2.76    | 7.62           | 1.97  | 3.88           | 1.71  | 2.92           | 2.59  | 6.71           | 2.01  | 4.04           | 1.71  | 2.92           | 2.39  | 5.71           |
| 4          | 2.62    | 6.86           | 2.24  | 5.02           | 1.76  | 3.10           | 2.26  | 5.11           | 2.06  | 4.24           | 1.72  | 2.96           | 2.49  | 6.20           |
| 5          | 2.72    | 7.40           | 2.03  | 4.12           | 1.63  | 2.66           | 2.49  | 6.20           | 2.01  | 4.04           | 1.89  | 3.57           | 2.50  | 6.25           |
| 6          | 2.57    | 6.60           | -     | -              | -     | -              | 2.56  | 6.55           | 2.02  | 4.08           | 2.15  | 4.62           | 2.46  | 6.05           |
| $\sum x$   | 15.00   |                | 10.54 |                | 8.11  |                | 15.02 |                | 11.37 |                | 11.29 |                | 14.96 |                |
| $\sum x^2$ | 22.35   |                | 22.35 |                | 13.21 |                | 37.68 |                | 21.96 |                | 21.37 |                | 37.34 |                |

$$H : M_1 = M_2 = M_3 \longrightarrow M_7.$$

Simple analysis of variance:  $n_1 = 6, n_2 = 5, n_3 = 5,$   
 $n_4 \longrightarrow n_7 = 6$

$$\alpha = 0.05, df = 6, 33, R: F \geq 2.42$$

$$\alpha = 0.01, df = 6, 33, R: F \geq 3.47$$

The null hypothesis is that there is no significant difference between the means of the Vo<sub>2</sub> values of the seven subjects.

$$1. \quad \sum x^2 = 192.02$$

$$2. \quad \frac{\sum T_j^2}{n_j} = 190.56$$

$$3. \quad \frac{T^2}{N} = \frac{86.29^2}{40} = \frac{7445.96}{40} = 186.15$$

$$4. \quad SS_b = \frac{\sum T_j^2}{nj} - \frac{T^2}{N} = 190.56 - 186.15 = 4.41$$

$$MS_b = \frac{4.41}{6} = 0.74$$

$$5. \quad SS_w = \sum x^2 - \frac{\sum T_j^2}{nj} = 192.02 - 190.56 = 1.46$$

$$MS_w = \frac{1.46}{33} = 0.044$$

$$F = \frac{MS_b}{MS_w} = \frac{0.74}{0.044} = 16.82$$

As  $F = 16.82$  is well beyond the region of rejection both at the 0.05 and 0.01 levels the null hypothesis must be rejected. The tentative conclusion that Equation I may be seen as a reasonably reliable indicator of  $Vo_2$  max for this sample must be withdrawn. No such conclusion may be made on the basis of data collected from the seven subjects in this experiment.

Equation (I) may predict  $Vo_2$  max values for five of the seven subjects reasonably reliably at the 0.05 and 0.01 levels when the predicted and actual values were compared on an individual basis.

However no generalisation may be made from individual comparison to a comparison involving all of the subjects in the sample.

#### 4.2 Heart Rate (H.R.)

In order to test the value of Bar-Or and Buskirk's equation

$$HR \text{ max} = 209.2 - 0.74 A$$

as a predictor of maximum heart rate, the HR max for each subject

based on the above equation was compared with HR max values obtained from Astrand and Rodahl's (1977) equation,

$$\text{HR max} = 220 - A.$$

These values also appear in Table 3:2.

A Pearson Correlation Coefficient was computed to estimate the strength of the relationship between the values of HR max calculated from Equation II and the Astrand and Rodahl formula.

Table 4:5    HR max values calculated from Equation II and Astrand and Rodahl.

| i   | HR (II)<br>max<br>x | HR (A&R)<br>max<br>y | x <sup>2</sup>    | y <sup>2</sup>    | xy               |
|-----|---------------------|----------------------|-------------------|-------------------|------------------|
| 1   | 173                 | 171                  | 29929             | 29241             | 29583            |
| 2   | 183                 | 185                  | 33489             | 34225             | 33855            |
| 3   | 176                 | 175                  | 30976             | 30625             | 30800            |
| 4   | 184                 | 186                  | 33856             | 34596             | 34224            |
| 5   | 180                 | 180                  | 32400             | 32400             | 32400            |
| 6   | 185                 | 188                  | 34225             | 35344             | 34780            |
| 7   | 184                 | 186                  | 33856             | 34596             | 34224            |
| n=7 | $\sum x=1265$       | $\sum y=1271$        | $\sum x^2=228731$ | $\sum y^2=231027$ | $\sum xy=229866$ |

Key:            i    = Subjects

HR (II)  
max            = Predicted HR<sub>max</sub> from Equation II

HR (A&R)  
max            = Predicted HR<sub>max</sub> from Astrand and Rodahl.

Astrand and Rodahl formula

$$r = \frac{sp}{\sqrt{SS_x SS_y}} \quad \text{where } SP = \sum xy - \frac{(\sum x)(\sum y)}{N}$$

$$SS_x = \sum x^2 - \frac{(\sum x)^2}{N}$$

$$SS_y = \sum y^2 - \frac{(\sum y)^2}{N}$$

Inserting the values of x and y in each of these formulae,

$$SP = 178.15$$

$$SS_x = 127.43$$

$$SS_y = 249.72$$

$$\begin{aligned} \% \quad r &= \frac{sp}{\sqrt{SS_x SS_y}} = \frac{178.15}{\sqrt{31821.819}} \\ &= \frac{178.15}{178.38671} \\ &= 0.999 \end{aligned}$$

A value of  $r = 0.99$  indicates a very close association between values calculated from Equation II by Bar-Or and Buskirk,

$$HR_{\max} = 209.2 - 0.74A,$$

and the formula proposed by Astrand and Rodahl,

$$HR_{\max} = 220 - A.$$

Therefore Equation II may be seen as a reliable predictor of Maximum Heart Rate for this sample.

On the other hand, because there is such a close relationship between the two formulae either one could be used with confidence to predict  $HR_{max}$ . Perhaps, because of its relative simplicity, the Astrand and Rodahl formula may be the more logical choice.

#### 4.3 Predicted Heart Rate from $Vo_2$ Max

In order to test the value of Roozbazar's (1974b) equation,

$$HR = 56.02 + 66.84 Vo_2 - 8.4 Vo_2^2$$

as a predictor of heart rate, the values of  $0.35 Vo_2 max$  were substituted into the equation for  $Vo_2$  values. The values of  $0.35 Vo_2 max$  is suggested in Roozbazar et al (1979) as that percentage, i.e. 35%, of maximal energy expenditure that can be allowed as the limit for eight hours of continuous work (p. 52).

Heart Rate was calculated using the above equation with  $Vo_2$  being  $0.35 Vo_2 max$  derived from Equation I.

These Heart Rate values are found in Table 4:6.

Heart Rate was then calculated using the above equation but this time  $Vo_2$  was  $0.35 Vo_2 max$  derived from Astrand's (1960) formula based on actual Heart Rate during each trial.

The Heart Rate values are found in Table 4:7.

A comparison of these Heart rate values may be seen in table 4:8. At first glance there appears to be some similarity between the two sets of HR values for Subjects 1,3, 4 and 6. The values in HR (I) are larger than HR (AST) for Subject 2, and smaller for subjects 5 and 7.

Table 4:6. Predicted Heart Rates from Equation III using  
values of  $Vo_2 = 0.35 \text{ } Vo_2 \text{ Max}$

| i | $Vo_{2\text{max}}$ | $Vo_2$ | $66.84 \text{ } Vo_2$ | $-8.4 \text{ } Vo_2^2$ | $+56.02$ | HR  |
|---|--------------------|--------|-----------------------|------------------------|----------|-----|
| 1 | 3.52               | 1.23   | 82.21                 | 12.71                  | 125.525  | 126 |
| 2 | 3.24               | 1.13   | 75.53                 | 10.73                  | 120.823  | 121 |
| 3 | 3.29               | 1.15   | 76.87                 | 11.11                  | 121.777  | 122 |
| 4 | 3.53               | 1.26   | 84.22                 | 13.34                  | 126.902  | 127 |
| 5 | 2.32               | 0.81   | 54.14                 | 5.51                   | 104.65   | 105 |
| 6 | 3.73               | 1.31   | 87.56                 | 14.42                  | 129.17   | 129 |
| 7 | 3.66               | 1.28   | 85.56                 | 13.76                  | 127.81   | 128 |

Key: i = subjects  
 $Vo_{2\text{max}}$  =  $Vo_2$  max from Equation I  
HR = Predicted heart Rate in beats per minute.



Table 4:7 Predicted Heart Rates from Astrand's (1960)  
Formula Using Values of  $Vo_2 = 0.35 Vo_2 \max$

| i | T | $Vo_{2\max}$ | $Vo_2$ | (b)    | (c)   | (a)    | HR  | i | T | $Vo_{2\max}$ | $Vo_2$ | (b)    | (c)   | (a)    | (HR) |
|---|---|--------------|--------|--------|-------|--------|-----|---|---|--------------|--------|--------|-------|--------|------|
| 1 | 1 | 3.42         | 1.20   | 80.21  | 12.10 | 124.13 | 124 | 5 | 1 | 3.42         | 1.20   | 80.21  | 12.10 | 124.13 | 124  |
|   | 2 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   | 2 | 3.07         | 1.07   | 71.52  | 9.62  | 117.92 | 118  |
|   | 3 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   | 3 | 3.31         | 1.16   | 77.53  | 11.3  | 122.25 | 122  |
|   | 4 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   | 4 | 3.31         | 1.16   | 77.53  | 11.3  | 122.25 | 122  |
|   | 5 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   | 5 | 2.78         | 0.97   | 64.83  | 7.9   | 112.95 | 113  |
|   | 6 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   | 6 | 3.07         | 1.16   | 77.53  | 11.3  | 122.25 | 122  |
| 2 | 1 | 2.81         | 0.98   | 65.50  | 8.07  | 113.46 | 113 | 6 | 1 | 3.10         | 1.09   | 72.86  | 9.98  | 118.9  | 119  |
|   | 2 | 2.89         | 1.01   | 67.51  | 8.57  | 114.96 | 115 |   | 2 | 3.83         | 1.34   | 89.57  | 15.08 | 130.5  | 131  |
|   | 3 | 2.89         | 1.01   | 67.51  | 8.57  | 114.96 | 115 |   | 3 | 3.57         | 1.25   | 83.55  | 13.13 | 126.45 | 126  |
|   | 4 | 2.81         | 0.98   | 65.5   | 8.97  | 113.46 | 113 |   | 4 | 3.74         | 1.31   | 87.56  | 14.42 | 129.17 | 129  |
|   | 5 | 2.89         | 1.01   | 67.51  | 8.57  | 114.96 | 115 |   | 5 | 3.40         | 1.20   | 80.21  | 12.10 | 124.13 | 124  |
|   |   |              |        |        |       |        |     |   | 6 | 3.32         | 1.16   | 77.53  | 11.3  | 122.25 | 122  |
| 3 | 1 | 3.32         | 1.16   | 77.53  | 11.3  | 122.25 | 122 | 7 | 1 | 4.51         | 1.58   | 105.61 | 20.97 | 140.66 | 141  |
|   | 2 | 3.95         | 1.38   | 92.24  | 15.0  | 132.26 | 132 |   | 2 | 3.91         | 1.37   | 91.57  | 15.77 | 131.82 | 132  |
|   | 3 | 3.91         | 1.37   | 91.57  | 15.77 | 131.82 | 132 |   | 3 | 4.91         | 1.72   | 114.96 | 24.85 | 146.13 | 146  |
|   | 4 | 3.57         | 1.25   | 83.55  | 13.13 | 126.45 | 126 |   | 4 | 3.91         | 1.37   | 91.57  | 15.77 | 131.82 | 132  |
|   | 5 | 3.83         | 1.34   | 89.57  | 15.08 | 130.5  | 131 |   | 5 | 4.08         | 1.43   | 95.58  | 17.18 | 134.42 | 134  |
| 4 | 1 | 5.08         | 1.78   | 118.98 | 26.61 | 148.38 | 148 |   | 6 | 3.91         | 1.37   | 91.57  | 15.77 | 131.82 | 132  |
|   | 2 | 3.61         | 1.26   | 84.22  | 13.34 | 126.9  | 127 |   |   |              |        |        |       |        |      |
|   | 3 | 3.44         | 1.20   | 80.21  | 12.10 | 124.13 | 124 |   |   |              |        |        |       |        |      |
|   | 4 | 4.35         | 1.52   | 101.6  | 19.41 | 138.21 | 138 |   |   |              |        |        |       |        |      |
|   | 5 | 3.85         | 1.35   | 90.23  | 15.31 | 130.95 | 131 |   |   |              |        |        |       |        |      |
|   | 6 | 3.69         | 1.30   | 86.9   | 14.2  | 128.72 | 129 |   |   |              |        |        |       |        |      |

Key: i = subjects

T = trials

$Vo_{2\max}$  =  $Vo_{2\max}$  from Astrand  
(1960)

(b) =  $66.84 Vo_2$

(c) =  $- 8.4 Vo_2^2$

(a) =  $56.02 + 66.84 Vo_2 - 8.4 Vo_2^2$

(HR) = Predicted HR in beats per  
minute.

Table 4:8      Table showing Heart Rate Values for Equation III with  
Vo2 = 0.35 Vo2 max derived from Equation I and  
Astrand (1960).

| i | T | HR (I) | HR (AST) |
|---|---|--------|----------|
| 1 | 1 | 126    | 124      |
|   | 2 | 126    | 127      |
|   | 3 | 126    | 127      |
|   | 4 | 126    | 127      |
|   | 5 | 126    | 127      |
|   | 6 | 126    | 127      |
| 2 | 1 | 121    | 113      |
|   | 2 | 121    | 115      |
|   | 3 | 121    | 115      |
|   | 4 | 121    | 113      |
|   | 5 | 121    | 115      |
| 3 | 1 | 122    | 122      |
|   | 2 | 122    | 132      |
|   | 3 | 122    | 132      |
|   | 4 | 122    | 126      |
|   | 5 | 122    | 131      |
| 4 | 1 | 127    | 148      |
|   | 2 | 127    | 127      |
|   | 3 | 127    | 124      |
|   | 4 | 127    | 138      |
|   | 5 | 127    | 131      |
|   | 6 | 127    | 129      |

| i | T | HR (I) | HR (AST) |
|---|---|--------|----------|
| 5 | 1 | 105    | 124      |
|   | 2 | 105    | 118      |
|   | 3 | 105    | 122      |
|   | 4 | 105    | 122      |
|   | 5 | 105    | 113      |
|   | 6 | 105    | 122      |
| 6 | 1 | 129    | 119      |
|   | 2 | 129    | 131      |
|   | 3 | 129    | 126      |
|   | 4 | 129    | 129      |
|   | 5 | 129    | 124      |
|   | 6 | 129    | 122      |
| 7 | 1 | 128    | 141      |
|   | 2 | 128    | 132      |
|   | 3 | 128    | 146      |
|   | 4 | 128    | 132      |
|   | 5 | 128    | 134      |
|   | 6 | 128    | 132      |

Both sets of values are shown in Figure 4:2 which illustrates the cluster wherein both sets of values are to be found and extremes of difference between the values.

However in order that a more in-depth comparison could be made it was deemed necessary to compare HR values from Equation III using  $Vo_2 = 0.35 Vo_2 \text{ max}$  from Equation I, and  $Vo_2 = 0.35 Vo_2 \text{ max}$  from the intersection of the regression of actual HR and predicted  $HR_{\text{max}}$  from Equation II for each subject.

Regressions of HR against  $Vo_2$  were computed for each subject from the results in Table 4:1 and Table 4:4. The regressions are presented below and the working may be found in Appendix 1.

HR  
(beats min<sup>-1</sup>)

notation: • =  $0.35 \dot{V}O_{2\max}$  (AST)

+ =  $0.35 \dot{V}O_{2\max}$  (I)

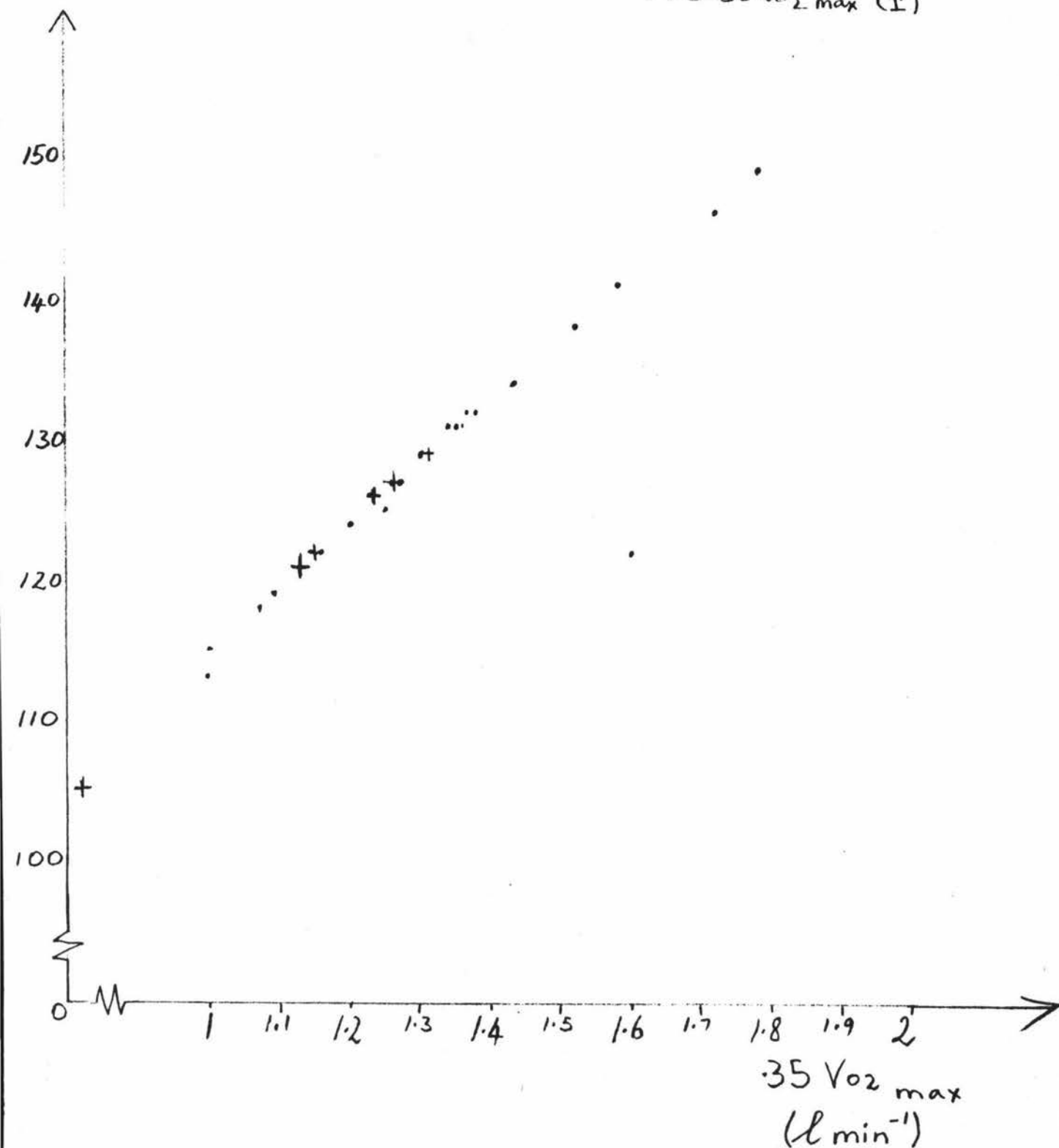


Figure 4:2 Showing Predicted Heart Rate against  $\dot{V}O_2$ .

|            |    |   |               |                 |
|------------|----|---|---------------|-----------------|
| Subject 1: | HR | = | 89.58 + 19.43 | Vo <sub>2</sub> |
| Subject 2: | HR | = | 134.24 + 6.15 | Vo <sub>2</sub> |
| Subject 3: | HR | = | 107.09 + 19.7 | Vo <sub>2</sub> |
| Subject 4: | HR | = | 55.7 + 37.13  | Vo <sub>2</sub> |
| Subject 5: | HR | = | 118.74 + 9.4  | Vo <sub>2</sub> |
| Subject 6: | HR | = | 92.4 + 23.2   | Vo <sub>2</sub> |
| Subject 7: | HR | = | -35.1 + 72.6  | Vo <sub>2</sub> |

By substituting values for HR max from Equation II into HR in the regressions the subjects' Vo<sub>2</sub> max was obtained.

|            |                     |                                       |        |
|------------|---------------------|---------------------------------------|--------|
| Subject 1: | 173 = 89.58 + 19.43 | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 4.29 |
| Subject 2: | 183 = 134.24 + 6.15 | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 7.92 |
| Subject 3: | 176 = 107.09 + 19.7 | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 3.59 |
| Subject 4: | 184 = 55.7 + 37.13  | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 3.46 |
| Subject 5: | 180 = 118.74 + 9.4  | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 6.52 |
| Subject 6: | 185 = 92.4 + 23.2   | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 4.42 |
| Subject 7: | 184 = -35.1 + 72.6  | Vo <sub>2</sub> , Vo <sub>2</sub> max | = 3.02 |

The next step was to calculate  $0.35 \text{ Vo}_2 \text{ max}$  from the above values and substitute this set of  $\text{Vo}_2$  into Equation III. The results of this calculation are shown in Table 4:9.

TABLE 4:9 Predicted HR from Equation III with  $\text{Vo}_2 = 0.35 \text{ Vo}_2 \text{ Max}$   
derived from HR max.

| i | $\text{Vo}_2 \text{ max}$ | $0.35 \text{ Vo}_2 \text{ max}$ | $\text{HR} = 56.02 + 66.84 \text{ Vo}_2 - 8.4 \text{ Vo}_2^2$ |       |
|---|---------------------------|---------------------------------|---------------------------------------------------------------|-------|
| 1 | 4.29                      | 1.50                            | 137                                                           | (126) |
| 2 | 7.92                      | 2.78                            | 177                                                           | (121) |
| 3 | 3.59                      | 1.26                            | 127                                                           | (122) |
| 4 | 3.46                      | 1.21                            | 125                                                           | (127) |
| 5 | 6.52                      | 2.28                            | 165                                                           | (105) |
| 6 | 4.42                      | 1.55                            | 139                                                           | (129) |
| 7 | 3.02                      | 1.06                            | 117                                                           | (128) |

When these values are compared with those for  $\text{HR} = 0.35 \text{ Vo}_2$  from Equation I (the figures in parentheses in Table 4:9) there appears to be less coincidence of values than in the comparison in Table 4:8. Again Subjects 2 and 5 showed widely different values of HR from the two procedures.

The mean of the values of HR (AST) (from Table 4:8) was calculated and these mean values were compared with HR values from  $\text{Vo}_2 = 0.35 \text{ Vo}_2 \text{ max}$  from Equation I and from actual HR in Table 4:9. The three sets of values appear in Table 4:10.

Table 4:10 H.R. from Equation III with  $Vo_2 = 0.35 Vo_2 \text{ max}$   
obtained from Equation I, Astrand (1960) and Actual HR.

| $HR = 56.02 + 66.84 Vo_2 - 8.4 Vo_2^2$ |       |                       |          |
|----------------------------------------|-------|-----------------------|----------|
| i                                      | HR(I) | $\overline{HR}$ (AST) | HR (DER) |
| 1                                      | 126   | 126                   | 137      |
| 2                                      | 121   | 114                   | 177      |
| 3                                      | 122   | 129                   | 127      |
| 4                                      | 127   | 133                   | 125      |
| 5                                      | 105   | 120                   | 165      |
| 6                                      | 129   | 125                   | 139      |
| 7                                      | 128   | 136                   | 117      |

Key:  $HR(I)$  where  $Vo_2 = 0.35 Vo_2 \text{ max} = 56.592 - 0.398A$ .

$\overline{HR}$  (Ast) = mean value of HR DERIVED FROM Astrand (1960)

HR (DER) = HR derived from regressions.

A Pearson Correlation Coefficient was computed to estimate the strength of the relation between the values of HR in Table 4:10. The first relationship to be estimated was between HR (I) and  $\overline{HR}$  (AST).

Let  $x = HR (I)$

$y = \overline{HR} (AST)$

$$r = \frac{SP}{\sqrt{SS_X SS_Y}}$$

$$\text{Where } SP = \sum xy - \frac{(\sum x)(\sum y)}{N}$$

$$SS_X = \sum x^2 - \frac{(\sum x)^2}{N}$$

$$SS_Y = \sum y^2 - \frac{(\sum y)^2}{N}$$

From the values in Table 4:10,

$$\begin{aligned}\sum x &= 858 & \sum y &= 883 \\ \sum x^2 &= 105580 & \sum y^2 &= 111723 \\ (\sum x)^2 &= 736164 & (\sum y)^2 &= 779689 \\ \sum xy &= 108432\end{aligned}$$

$$SP = 201.43$$

$$SS_x = 413.72$$

$$SS_y = 338.86$$

$$r = \frac{201.43}{\sqrt{(413.72)(338.86)}} = 0.54$$

The second relationship to be estimated was between HR (I) and HR (DER).

Let  $X = \text{HR (I)}$

$Y = \text{HR (DER)}$

From the values in Table 4:10,

$$\begin{aligned}\sum x &= 858 & \sum y &= 987 \\ \sum x^2 &= 105580 & \sum y^2 &= 142087 \\ (\sum x)^2 &= 736164 & (\sum y)^2 &= 974169 \\ \sum xy &= 120280\end{aligned}$$

$$SP = 698$$

$$SS_x = 413.72$$

$$SS_y = 2920$$

$$r = \frac{698}{\sqrt{(413.72)(2920)}} = 0.64$$



The third relationship to be estimated was between HR (AST) and  $\overline{\text{HR}}$  (DER).

$$\text{Let } X = \overline{\text{HR}} \text{ (AST)}$$

$$Y = \text{HR (DER)}$$

From the values in Table 4:10,

$$\sum x = 883$$

$$\sum y = 987$$

$$\sum x^2 = 111723$$

$$\sum y^2 = 142087$$

$$(\sum y)^2 = 779689$$

$$(\sum x)^2 = 974169$$

$$\sum xy = 123535$$

$$\text{SP} = -968$$

$$\text{SS}_x = 338.86$$

$$\text{SS}_y = 2920$$

$$r = \frac{-968}{(338.86)(2920)} = -0.97$$

So the strength of the relation between the three sets of HR values are:

$$\text{HR (I) and } \overline{\text{HR}} \text{ (AST) - } r = 0.54, r/\sigma_r = 1.32$$

$$\text{HR (I) and HR (DER) - } r = 0.64, r/\sigma_r = 1.57$$

$$\overline{\text{HR}} \text{ (AST) and HR (DER) - } r = -0.97, r/\sigma_r = -2.38$$

A correlation coefficient of  $r = 0.54$  between HR (I) and  $\overline{\text{HR}}$  (AST) was no surprise, given a casual glance at those values in Table 4:10. A coefficient of  $r = 0.64$  between HR (I) and HR (DER) was surprising given the disparity between values for Subjects 2 and 5. However on the basis of these two coefficients, Equation III with  $0.35 \text{ Vo}_2 \text{ max}$  substituted for  $\text{Vo}_2$ , whether from Equation I, or from Astrand's (1960) data or from calculation of  $\text{Vo}_2 \text{ max}$  from regression of actual Heart Rate and values, may be seen as a reasonably reliable predictor of Heart

Rate for this sample. But because of the reservations expressed in 4.1 about the appropriateness of the use of Equation I as a predictor of  $\text{Vo}_2 \text{ max}$  for this sample, any support for Equation III using  $\text{Vo}_2 = 0.35 \text{ Vo}_2$  from Equation I must be guarded.

A correlation coefficient of  $r = -0.97$  between  $\overline{\text{HR}}$  (AST) and HR (DER) indicates that the relation between the two methods of obtaining  $0.35 \text{ Vo}_2 \text{ max}$  is very strong. The strength of the relationship was surprising : it was anticipated that there would be some measure of relation but not one of this size. It appears to confirm a preference for obtaining  $\text{Vo}_2 \text{ max}$  from the Astrand data rather than from Equation I. However, given a sample size of seven subjects this confirmation must necessarily be viewed conservatively.

## CHAPTER 5

### CONCLUSIONS

#### 5.1 Equation I - Vo<sub>2</sub>max

For this sample of seven males the equation,

$$\text{Vo}_2 \text{ max} = 56.592 - 0.398 A$$

does not appear to be a reliable predictor of maximum oxygen consumption, given the values obtained in the experiment. However Equation I does appear to be a reasonably reliable predictor of Vo<sub>2</sub> max for five of the subjects, when results are compared on an individual basis. The two subjects for whom Equation I was not a reasonably reliable predictor of Vo<sub>2</sub> max were subjects 2 and 5.

Subject 2 is 35 years of age and weighs 76 kg. He is a non smoker, having given up the habit about ten years ago. At the time of the experiment the subject had taken little exercise for almost a year due to a back ailment. The subject's Vo<sub>2</sub> max predicted from Astrand's (1960) data using heart rate and body weight, following each trial, was consistently lower than that predicted by Equation I, 3.2 L min<sup>-1</sup>.

One possible explanation for the over-estimation of predicted Vo<sub>2</sub> max from Equation I against Vo<sub>2</sub> max measured from HR may be that the subject's weight (76 kg) is light in relation to his height (approx. 178 cm). The subject is lean, but not what may be described as skinny. At a load of 900 watts the subject experienced little excessive strain although his heart rate over the five trials ranged from 146-149 beats per minute.

Another possible explanation for the over-estimation may be linked to the subject's lack of exercise over the previous year. It is possible that the subject's heart rate over the five trials was higher than it would have been if the subject had taken exercise constantly over the previous year, i.e. a sort of practice effect.

Subject 5 is 40 years of age, weighs 58 kg and is 178 cm tall. He is extremely lean, possibly skinny, and is a heavy cigarette smoker. The only exercise he takes is when he occasionally cycles to work from his home, a distance of approximately 6 km. The subject's  $\text{Vo}_2$  max predicted from Astrand's (1960) data using heart rate and body weight, following each trial, was consistently higher than that predicted by Equation I,  $2.3 \text{ L min}^{-1}$ .

One possible explanation for this discrepancy may lie with the fact that the subject completed his trials at a load of 150 watts, rather than at approximately 120 watts which was the originally recommended load. The originally recommended load was approximately 2 watts per kg of body weight, which for this subject would have yielded a load of 116 watts, rounded to 120 watts on the ergometer's mechanical work rate output meter. However a work load of 120 watts did not raise the subject's heart rate to anything approaching 140 beats per minute, the value stated in Chapter Three to be the lower threshold of heart rate for the experiment.

It is possible, therefore, that at a work load of 150 watts the subject was working at a level which was much higher than he should have been, even though he reported no strain or extreme discomfort.

Indeed his average oxygen consumption over the six trials was 82% of  $Vo_2$  max predicted from Equation I which indicates that the subject was working extremely hard. Even using  $Vo_2$  max calculated from Astrand's (1960) data, the subject's average oxygen consumption over the six trials was 60% of  $Vo_2$  max, still very high.

It is felt then that given a work load of 120 watts, this subject may have yielded values for  $Vo_2$  max closer to those predicted by Equation I.

### 5.2 Equation II - HR max

For this sample of seven males the equation,

$$HR_{\max} = 209.2 - 0.74 A$$

appears to be a reliable predictor of maximum heart rate. However as stated in Chapter 4.2 Astrand and Rodahl's (1977) formula for  $HR_{\max}$ , where  $HR_{\max} = 220 - A$ , may be a preferred formula to use, given its relative simplicity.

### 5.3 Equation III - HR

Because of its reliance on  $Vo_2$  max values from Equation I, Equation III,

$$HR = 56.02 + 66.84 Vo_2 - 8.4 Vo_2^2 \quad \text{where}$$

$$Vo_2 = 0.35 Vo_2 \text{ max,}$$

can be given only limited support in this research. However given a much larger, and perhaps more homogeneous, sample of subjects Equation I may have proved to be a reliable predictor of  $Vo_2$  max. If this had been the case then Equation III may well have been shown to be a reliable predictor of HeartRate for occupational limits.

These results do, however, appear promising and point to the need for further research in this area.

Equation III appeared to have more predictive value when the values of  $0.35 \text{ Vo}_2 \text{ max}$  were obtained from  $\text{Vo}_2 \text{ max}$  (Astrand, 1960) and from regressions of HR over  $\text{Vo}_2$  for each subject in the sample. While this is promising, it does raise a rather obvious point: the intention of Equation III is to predict Heart Rate without having to measure it for each subject. Because this equation aims to predict occupational levels of HR, it is obvious that it defeats such a purpose to measure workers' HR and  $\text{Vo}_2$  while they are at work, in order to ascertain the workers'  $\text{Vo}_2 \text{ max}$ .

The focus for future research in this area should be the predictive Equations I and III, but especially Equation I. When the constants  $56.592 - 0.398$  are verified, or modified, so that values of  $\text{Vo}_2 \text{ max}$  can be obtained from Equation I with more confidence than that shown in this Research Report, then Equation III may also be used with confidence to predict Heart Rate for occupational classifications.

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Appendix 1. Computation of regression of HR against Vo2 for each subject.

Subject 1

| Vo <sub>2</sub><br>X | HR<br>Y | x<br>X-X | y<br>Y-Y | xy    | x <sup>2</sup> | y <sup>2</sup> |
|----------------------|---------|----------|----------|-------|----------------|----------------|
| 1.81                 | 124     | -0.69    | -14.17   | 9.777 | 0.476          | 200.79         |
| 2.52                 | 140     | 0.02     | 1.83     | 0.037 | 0.0004         | 3.35           |
| 2.76                 | 140     | 0.26     | 1.83     | 0.476 | 0.068          | 3.35           |
| 2.62                 | 141     | 0.12     | 2.83     | 0.340 | 0.144          | 8.01           |
| 2.72                 | 143     | 0.22     | 4.83     | 1.063 | 0.0484         | 23.33          |
| 2.57                 | 141     | 0.07     | 2.83     | 0.198 | 0.0049         | 8.01           |

$$\sum X=15 \quad \sum Y=829$$

$$\sum xy=11.89 \quad \sum x^2=0.61 \quad \sum y^2=246.84$$

$$\bar{x}=2.5 \quad \bar{y}=138.17$$

$$y = a + bx \quad b = \frac{\sum xy}{\sum x^2} = \frac{11.89}{0.61} = 19.43$$

$$\begin{aligned} a &= \bar{y} - b (\bar{x}) = 138.17 - 19.43 (2.5) \\ &= 138.17 - 48.59 \\ &= 89.58 \end{aligned}$$

$$^{\circ} Y = 89.58 + 19.43 x$$

$$\begin{aligned} \text{Standard error of estimate} &= \sqrt{\frac{246.84 - 19.43 (11.89)}{4}} \\ &= \sqrt{3.954} \\ &= 1.99 \end{aligned}$$

### Subject 2

| X    | Y   | x     | y    | xy    | x <sup>2</sup> | y <sup>2</sup> |
|------|-----|-------|------|-------|----------------|----------------|
| 2.36 | 148 | 0.252 | 0.8  | 0.202 | 0.064          | 0.64           |
| 1.94 | 146 | -0.17 | -1.2 | 0.204 | 0.029          | 1.44           |
| 1.97 | 146 | -0.14 | -1.2 | 0.168 | 0.02           | 1.44           |
| 2.24 | 149 | 0.13  | 1.8  | 0.234 | 0.17           | 3.24           |
| 2.03 | 147 | -0.08 | -0.2 | 0.016 | 0.006          | 0.04           |

$$\sum x = 10.54 \quad \sum y = 736$$

$$\bar{x} = 2.108 \quad \bar{y} = 147.2$$

$$\sum xy = 0.824 \quad \sum x^2 = 0.134 \quad \sum y^2 = 6.8$$

$$b = \frac{0.824}{0.134} = 6.15$$

$$a = 147.2 - 6.15(2.108)$$

$$= 147.2 - 12.96$$

$$= 134.24$$

$${}^{\circ}Y = 134.24 + 6.15x$$

$$\text{Standard error} = \sqrt{\frac{6.8 - 6.15(0.824)}{3}}$$

$$= 0.76$$

### Subject 3

| X    | Y   | x     | y  | xy    | x <sup>2</sup> | y <sup>2</sup> |
|------|-----|-------|----|-------|----------------|----------------|
| 1.50 | 137 | -0.12 | -2 | 0.24  | 0.014          | 4              |
| 1.51 | 137 | -0.11 | -2 | 0.22  | 0.012          | 4              |
| 1.71 | 138 | 0.09  | -1 | -0.09 | 0.008          | 1              |
| 1.76 | 144 | 0.14  | 5  | 0.70  | 0.02           | 25             |
| 1.63 | 139 | 0.01  | 0  | 0     | 0.001          | 0              |

$$\sum x = 8.11 \quad \sum y = 695$$

$$\bar{x} = 1.62 \quad \bar{y} = 139$$

$$\sum xy = 1.07 \quad \sum x^2 = 0.0543 \quad \sum y^2 = 34$$

$$b = \frac{1.07}{0.0543} = 19.7$$

$$a = 139 - 19.7(1.62)$$

$$= 107.09$$

$$SE = \sqrt{\frac{34 - 19.7(1.07)}{3}}$$

$${}^{\circ}Y = 107.09 + 19.7x$$

$$= 2.08$$

Subject 4

$$\sum x = 15.02$$

$$\bar{x} = 2.503$$

$$\sum y = 892$$

$$\bar{y} = 148.67$$

$$\sum xy = 2.97$$

$$\sum x^2 = 0.08$$

$$\sum y^2 = 216.44$$

$$b = \frac{2.97}{0.08} = 37.13$$

$$a = 148.67 - 37.13 (2.503)$$

$$= 55.7$$

$$y = 55.7 + 37.13x$$

Standard error:

$$\sqrt{\frac{216.44 - 37.13 (2.97)}{4}} = 5.15$$

Subject 5

$$\sum x = 11.37$$

$$\bar{x} = 1.89$$

$$\sum y = 819$$

$$\bar{y} = 136.5$$

$$\sum xy = 3.85$$

$$\sum x^2 = 0.41$$

$$\sum y^2 = 135.5$$

$$b = \frac{3.85}{0.41} = 9.4$$

$$a = 136.5 - 9.4 (1.89)$$

$$= 118.74$$

$$y = 118.74 + 9.4x$$

S x.y

$$= \sqrt{\frac{135.5 - 9.4 (3.85)}{4}} = 4.98$$

Subject 6

$$\sum x = 11.29$$

$$\bar{x} = 1.88$$

$$\sum y = 816$$

$$\bar{y} = 136$$

$$\sum xy = 2.55$$

$$\sum x^2 = 0.11$$

$$\sum y^2 = 176$$

$$b = \frac{2.55}{0.11} = 23.2$$

$$a = 136 - 23.2 (1.88)$$

$$= 92.4$$

$$y = 92.4 + 23.2x$$

Sx.y

$$= \sqrt{\frac{176 - 23.2 (2.55)}{4}} = 5.4$$

Subject 7

$$\sum x = 14.96$$

$$\bar{x} = 2.49$$

$$\sum y = 874$$

$$\bar{y} = 145.67$$

$$\sum xy = 3.63$$

$$\sum x^2 = 0.05$$

$$\sum y^2 = 371.33$$

$$b = \frac{3.63}{0.05} = 72.6$$

$$a = 145.67 - 72.6 (2.49) \\ = - 35.1$$

$${}_oY = - 35.1 + 72.6X$$

$$S_{x.y} = \sqrt{\frac{371.33 - 72.6 (3.63)}{4}} = 5.19$$