PREDICTING PEAK OXYGEN UPTAKE FROM RATINGS OF
PERCEIVED EXERTION DURING SUBMAXIMAL
CYCLE ERGOMETRY

THESIS

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By

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The purpose of this study was to predict VO$_{2peak}$ using ratings of perceived exertion (RPE), heart rate (HR), and percent fat (PFAT). Subjects were males ($n=60$) (PFAT, $M\pm SD = 14.4 \pm 6.1$) and females ($n=67$) (PFAT, $M\pm SD = 23.4 \pm 4.9$) with ages ranging from 18 to 33 years. Subjects performed an incremental cycle ergometer protocol and RPE, HR and VO$_2$ were measured at each stage until VO$_{2peak}$ was achieved. Mean RPE and HR at the submaximal workload of 100 watts were, (RPE100) $M=12.7 \pm 2.6$ and (HR100) $M=146.9 \pm 24.7$ respectively. Correlations ($p<.001$) with VO$_{2peak}$ were -.75 (PFAT), -.66 (HR100), -.67 (RPE100). The multiple correlation using PFAT, HR100, and RPE100 as predictors of VO$_{2peak}$ was .83 ($SEE= 5.28$ ml·kg BW$^{-1}$·min$^{-1}$). Each predictor contributed to the correlation ($p<.01$). The results indicate that PFAT combined with exercise responses of RPE and HR provide valid estimates of VO$_{2peak}$ with a relatively small $SEE$.
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CHAPTER I

INTRODUCTION

The measurement of a maximal oxygen uptake (VO$_{2\text{max}}$) is considered to be the criterion method of determining cardiorespiratory fitness level (Mitchell & Blomqvist, 1971; Taylor, Buskirk & Henschel, 1955; Wahlund, 1948). A direct assessment of maximal aerobic power is often used by physiologists to help determine a patient's diagnosis, set training guidelines for athletes, or to prescribe exercise for fitness program participants. To directly measure a person's VO$_{2\text{max}}$, or more appropriately the highest value for oxygen consumption measured in any single test (VO$_{2\text{peak}}$), requires time, expensive equipment, and cooperation on the part of the subject as this procedure demands maximal effort and therefore causes discomfort to the subject.

Several studies have shown that the use of a person's perception of effort is a good indicator of physical strain and therefore could be used in submaximal situations to complement physiological measures such as heart rate (Borg, 1962; Borg & Noble, 1974; Pandolph, Cafarelli, Noble, & Metz, 1972).

The use of ratings of perceived exertion (RPE) was pioneered by Dr. Gunnar Borg, a professor of psychology at the University of Stockholm. Borg investigated the relationship between sensation of effort and an easily quantifiable physical stimulus. He used the cycle ergometer to provide a known physical exercise intensity and a readily obtainable physiological response, heart rate (Borg, 1962). He developed a simple rating scale which used the
subject’s recorded perceptions of how intense the exercise felt and assigned them numeric scores. Borg and Noble (1974) suggested that heart rate (HR) can be predicted from the use of what has become known as the Borg or RPE scale by multiplying the RPE by 10. Using RPE to help determine when a subject is near their maximum heart rate could be useful because many physiologists use predicted maximal HR as an indicator of when a subject has reached his highest level of oxygen consumption (VO2peak) during a graded exercise test (Borg & Linderholm, 1970; Morgan & Borg, 1976).

While it has never been suggested that there is a causal relationship between RPE and HR, correlations of .80 to .90 between RPE and HR that have been computed over a wide range of work loads, demonstrate that a high percentage of common variance is shared by RPE and HR (Noble & Borg, 1972). A linear relationship exists between HR and VO2, and given the linear relationship between RPE and HR, it is not surprising that RPE is also linearly related to VO2 (Noble & Borg, 1972).

Methods for estimating VO2peak from submaximal testing were developed by several researchers (Åstrand & Ryhming, 1954; Margaria, Aghemo, & Rovelli, 1965) and, although some limitations in accuracy have been reported (Davies, 1968; Rowell, Taylor, & Wang, 1964), predicted VO2peak is still one of the most frequently used estimates of physical capacity (Ljunggren & Johansson, 1988). Typical standard errors (SEE) reported in studies using a cycle ergometer protocol ranged from 0.172 to 0.430 L·min⁻¹ (Åstrand & Ryhming, 1954; Fox, 1973; Mastropaolo, 1970; Siconolfi, Cullianane, Carleton, & Thompson, 1982). Åstrand and Ryhming (1954) presented a method of predicting VO2peak using HR obtained during a single stage submaximal bike test. This HR along with
the corresponding work load was used to predict $VO_{2\text{peak}}$ using a nomogram. This predictive test is still widely used today in clinical and fitness settings and is based upon the linear relationship between heart rate and $VO_2$.

Most of the predictive tests reported in the literature do not present cross-validation results (Falls, Ismail & Macleod, 1966; Fox, 1973; Mastropaolo, 1970) and many provide no measure of the $SEE$ (Doolittle & Bigbee, 1968; Hermiston & Faulkner, 1971; Maksud & Coutts, 1971).

Wilmore et al. (1986) conducted a study using RPE, heart rate, and power output to predict maximal oxygen uptake employing a submaximal cycle ergometer protocol. Sixty-two subjects (27 male, 35 female, mean age 23 ± 3 years, age range 15 to 31) were tested using a protocol consisting of four 3-minute stages that started at either 29, 59, 88, or 118 watts and progressed by increments of 29 watts for each subsequent stage. For the total sample, the correlation with actual $VO_{2\text{max}}$ was $r = .85$ ($SEE = 0.308$) and a mean difference of 0.020 L·min$^{-1}$.

A similar study utilizing a treadmill protocol yielded far more modest results with regard to correlations and standard errors (Wilmore et al., 1985). Wilmore and associates concluded that both studies provided new approaches to the prediction of aerobic capacity that are reliable and, while useful for classification purposes, may not provide acceptable accuracy in prediction of aerobic capacity for certain scientific purposes.

While there had been some investigation into the role that a subject’s fitness level played in the prediction of $VO_{2\text{peak}}$ (Ljunggren & Johansson, 1988), the present study investigated variables that were related to a subject’s fitness but were also easily obtained and quantified. Data such as height, weight,
gender, age and lean body mass were combined with a self-reported physical activity score and were analyzed to determine their success in predicting a subject's $VO_{2\text{peak}}$.

A recent study (Jackson et al., 1990) investigated the prediction of $VO_{2\text{peak}}$ without the use of exercise testing. The study involved over 2,000 subjects. Jackson and his colleagues used age, gender, exercise history, and either percent fat (PFAT), as measured by skinfold calipers, or body mass index (BMI) as prediction variables. The results of the Jackson study (Jackson et al., 1990) confirmed that the non-exercise models were as accurate as established submaximal treadmill prediction models with correlations from .77 to .79 and standard errors of the estimate from 5.2 to 5.5 ml·kg·BW$^{-1}$·min$^{-1}$. PFAT had the highest correlation ($r = -.68$) with measured $VO_{2\text{peak}}$, more so than any other variable used.

Storer, Davis and Caiozzo (1990) reported correlation values for multiple regression equations which predicted $VO_{2\text{peak}}$ from maximal work rate, body weight, and age, of .92 and .95 for male and female subjects respectively. Their study involved administering a graded exercise test (GXT) to subjects while the subjects pedalled on a cycle ergometer. Stages of the test increased in 15 watt·min$^{-1}$ increments. The results of their study lend support to the use of cycle ergometer protocols for the purpose of predicting $VO_{2\text{peak}}$.

The present study has attempted to build on the investigations of Åstrand and Ryhming (1954), Morgan and Borg (1976), Wilmore et al. (1986), and Jackson et al. (1990). The sample size was increased in comparison with those studies listed above which used some form of exercise as a testing method, the purpose being to produce higher correlations and lower standard
errors of $VO_{2peak}$. The present investigation paralleled the above "non-exercise" model (Jackson et al., 1990), in the sense that a PFAT variable was added to the $VO_{2peak}$ prediction equation.

Statement of Problem

The problems of this study were (1) to determine the validity of using ratings of perceived exertion during submaximal cycle ergometry as a predictor of peak oxygen uptake; and (2) to determine if using RPE, HR and percent body fat is a valid and useful method for the prediction of $VO_{2peak}$ during submaximal cycle ergometry.

Purpose and Objectives

1. To determine the validity of using submaximal RPE during cycle ergometry to predict peak oxygen uptake.
2. To develop a regression equation incorporating RPE, HR and percent body fat to predict peak oxygen uptake.

Hypothesis

The working hypotheses were:

1. RPE at submaximal work loads is related to $VO_{2peak}$.
2. RPE, combined with the variables heart rate and percent body fat, would provide a valid method for estimating $VO_{2peak}$.
Definition of Terms

1. *Graded Exercise Test (GXT)*-- The test protocol of this investigation involved the subject riding an electronic cycle ergometer at three submaximal work rates followed by 20 (25 for males) Watt per minute increases in work rate until the subject reached volitional fatigue.

2. *Maximal Oxygen Uptake (VO$_{2\max}$)*-- The maximal volume of oxygen that can be utilized by an individual during strenuous exercise; this is determined by a plateau of VO$_2$, despite an increase in work rate.

3. *Peak Oxygen Uptake (VO$_{2\text{peak}}$)*-- The highest value for oxygen consumption that was measured during the GXT protocol used in this investigation. Cycling protocols usually do not elicit a maximal oxygen uptake due to the onset of acute leg fatigue prior to any cardiorespiratory limitations.

4. *Rating of Perceived Exertion (RPE)*-- A psycho-physical assessment, derived from a rating scale employed during an exercise test, which uses a subject's recorded perceptions of how intense the exercise feels and assigns these perceptions numeric scores.

5. *Volitional Fatigue* -- The point at which a subject can no longer maintain the required pedal cadence during exercise even with strong verbal encouragement.
Limitations

Listed below are the factors that may have confounded the results of the study.

1. Motivation of subjects and their compliance with the test protocol was often beyond the control of the investigator. However, strong verbal encouragement was consistently provided during testing, in order to obtain a maximal effort from each subject.

2. Dietary and exercise habits of subjects before the test were not controlled. All subjects were instructed to be 2 hours post-prandial and not to exercise at least 2 hours before the test.
CHAPTER II

REVIEW OF RELATED LITERATURE

In the following chapter, previous research in the area of predicting maximum oxygen consumption will be reviewed. It is the purpose of this review to provide information that directed the design and planning of the present investigation.

When measured under standardized conditions, maximal oxygen uptake (VO$_{2\text{max}}$) is an highly reproducible ($r = .95$) physiological variable (Taylor et al., 1955). Determination of VO$_{2\text{max}}$ in both clinical and health-promotion settings has become accepted as the single best criterion of cardiorespiratory endurance capacity (Mitchell & Blomqvist, 1971; Mitchell, Sproule & Chapman, 1958). However, numerous factors, such as expensive computer-aided equipment, adequate facilities, risk involved in maximal effort, and supply of willing and cooperative subjects, have made the direct determination of VO$_{2\text{max}}$ often a costly and difficult procedure. Because of these factors much investigation has been done to develop submaximal tests that could provide accurate estimations of VO$_{2\text{max}}$ without the various difficulties associated with direct assessment methods (Åstrand & Ryhming, 1954; Jackson et al., 1990; Wilmore et al., 1986).
Submaximal estimation of VO$_{2\text{peak}}$ using heart rate.

Much of the early work done in the area of VO$_{2\text{max}}$ estimation was based on the assumption that a linear relationship exists between heart rate and VO$_2$. Indeed, Åstrand and Ryhming (1954) presented a nomogram where an individual's maximal attainable oxygen intake could be estimated from heart rate and work rate reached during a submaximal test. The work tests could either be performed with a step-test or utilizing a cycle ergometer. Cycle ergometry was the preferred mode of exercise because previous investigations by Wahlund (1948), later confirmed by Åstrand and Ryhming, indicated that the mechanical efficiencies measured during cycling were fairly consistent ($\pm 6\%$) in two-thirds of the subjects. Similar mechanical efficiencies were reported for both men and women. There was concern that the nomogram was invalid when used with a non-homogeneous (asymptomatic, 18-30 yr old) group of subjects. The reason being that, the population investigated in the Åstrand and Ryhming study consisted of healthy males and females, with an age range of 18-30 years. Åstrand (1960) later conducted an investigation that took into account age as a factor. Results of that study, suggested some modifications that would account for the overestimation of VO$_2$ in older subjects that was occurring with the use of the original nomogram (Åstrand & Ryhming, 1954).

Åstrand and Ryhming's nomogram proved to be a suitable predictor ($r = .65$) of maximum oxygen uptake according to Glassford, Baycroft, Sedgwick and MacNab (1965). The predictability of the nomogram was also confirmed by Teräslinna, Ismail and MacLeod (1966) as long as the nomogram was corrected for age. A correlation of .69 was calculated between maximum
oxygen uptake and predicted maximum oxygen uptake using the original nomogram, and when corrected for age the correlation was .92.

Some investigators discovered severe limitations in the prediction of VO$_{2\text{max}}$ when submaximal heart rates alone were used in the prediction equation (Davies, 1968; Rowell et al., 1964). The studies that use submaximal heart rates as a sole predictor of VO$_{2\text{max}}$ (Åstrand & Ryhming, 1954; Fox, 1973; Teräslinna et al., 1966) are of course assuming a linear relationship between heart rate and VO$_2$. One issue with the Åstrand-Ryhming nomogram that troubled investigators was the assumption of a linear relationship between heart rate and VO$_2$ at submaximal work rates up to and including maximal levels (Davies, 1968). Critics of this assumption not only point out the apparent asymptotic pattern of heart rate response as one approaches VO$_{2\text{max}}$ (Davies, 1968), they also note other factors that could affect heart rate at any given level of submaximal work (Rowell et al., 1964). The relationship between heart rate and VO$_2$ does appear to be linear at low to moderate work rates (Davies, 1968). However, at near maximum levels the relationship begins to deteriorate and the curve flattens out, becoming asymptotic, leading to higher VO$_2$ values at the same predicted maximum heart rates (Davies, 1968; Wyndham et al., 1959). This leads to a underestimation of VO$_{2\text{max}}$ from the Davies data (1968) of about 1,200 ml·min$^{-1}$ at the 95% confidence level if the HR-VO$_2$ line is extrapolated to an observed HR maximum. Compared to the error that would occur due to random variation in measurements of cardiac frequency reported on these same subjects, this error is highly significant ($p< .001$) and constitutes a serious limitation to methods which try to predict VO$_2$ from data collected at submaximal levels of exercise (Davies, 1968).
Other investigators questioned the effect other factors had on subjects' heart rate and their submaximal heart rate specifically. One such study (Rowell et al., 1964) investigated the environmental stresses placed upon subjects and the changes in the subjects physiological state resulting from these stresses. What effect these changes had on the prediction of $\text{VO}_{2\text{max}}$ via submaximal heart rate was subsequently investigated (Rowell et al., 1964). Four groups of subjects were identified from a population of athletic and sedentary college students ranging in age from 18 to 24 years. In sedentary subjects, the Åstrand-Ryhming nomogram underestimated actual maximum $\text{VO}_2$ by 27% ($SD \pm 7\%$) and 14% ($SD \pm 7\%$) before and after 2.5 to 3 months of physical training, respectively. The nomogram also underestimated $\text{VO}_{2\text{max}}$ in a group of endurance athletes by 5.6 ± 4%. Procedural adaptation had a significant effect on prediction from the subjects’ first attempt to their second ($p = .02$) resulting in a more accurate prediction of $\text{VO}_{2\text{max}}$. There was also a 7% ($p = .001$) greater underestimation of $\text{VO}_{2\text{max}}$ with prediction by extrapolation and a 6% greater underestimation ($p = .001$) with prediction from the nomogram under the added stress of vascular catheterization in trained subjects. Overall, there was a marked trend toward improved accuracy of prediction with increased level of physical training. This study (Rowell et al., 1964) also found a decreased $\text{VO}_{2\text{max}}$ of 4% by removing 14% of circulating hemoglobin but no change in submaximal heart rates or predicted $\text{VO}_{2\text{max}}$ over an 8-day period. The respiratory quotient (RQ) to $\text{VO}_2$ relationship showed no reliable basis for prediction of $\text{VO}_{2\text{max}}$. These results suggest that reliance solely on submaximal heart rate as a predictor of $\text{VO}_{2\text{max}}$ would be unadvisable (Rowell et al., 1964).
Acknowledging these limitations, Fox (1973) conducted an investigation that predicted VO\textsubscript{2max} from a single submaximal heart rate determination. Though Fox was predicting VO\textsubscript{2max} from HR (given the asymptotic nature of the HR-VO\textsubscript{2} relationship), his prediction was only dependent upon the relationship that exists between a single submaximal heart rate determination and VO\textsubscript{2max}. He was not attempting to extrapolate the HR-VO\textsubscript{2} curve to a predicted maximum. Fox's technique was kept simple, involving a single 5-minute submaximal work rate (150 watts) and one submaximal variable (heart rate) measured on 87 untrained, healthy men. This yielded a moderately high correlation between the above variables of \( r = .76 \). While Fox concluded that the accuracy of his prediction was adequate, he found this to be true only for classification purposes. He based this conclusion on a comparison of his data with those of earlier investigations (Ekblom, 1970; Teräslinna et al., 1966).

Submaximal estimation of VO\textsubscript{2peak} with multiple predictors.

Due to the underestimations obtained when using simple regression or extrapolation of submaximal heart rate, the need for a more accurate method of predicting VO\textsubscript{2max} was desired. A pair of studies supported the theory of gaining increased accuracy by employing multiple regression in the prediction process. Hermiston and Faulkner (1971) and Mastropolo (1970) both presented results which seemed to confirm that multiple regression would develop a better prediction equation for VO\textsubscript{2max} by investigating a wide variety of respiratory and cardiovascular variables at submaximal work loads.

Mastropolo (1970) investigated the possibility of obtaining a significantly higher correlation with actual VO\textsubscript{2max} by using multiple variables in the
regression equation and comparing the results with simple regression techniques. Mastropaolo investigated a group of middle aged men (43 to 61 yrs of age) which at the time was apparently one of a few studies done exclusively on a population of that age group. The results of this study indicated that multiple regression using numerous physiological variables provided a high correlation between predicted and actual VO$_{2\text{max}}$ (multiple $r = .93$, SEE = 0.172 l-min$^{-1}$). The variables used in the equation included respiratory exchange ratio, work rate, HR, diastolic blood pressure, volume of expired air, and fraction of expired O$_2$. A comparison between the Mastropaolo (1970) prediction and one using simple regression as described by Åstrand (1960) yielded a significantly better prediction of VO$_{2\text{max}}$ in favor of multiple regression, using Fisher's transformation test ($Z_x = 2.32$, $p < .05$) as the method of comparison. The use of multiple regression may reduce fallibility in the prediction of VO$_{2\text{max}}$ by relying on more than a single physiological variable in the prediction equation (Mastropaolo, 1970).

Certain anthropometric and demographic variables such as age and fat-free weight were also used in hopes of improving the prediction capabilities of the equation (Hermiston & Faulkner, 1971). This was significant in that it allowed the investigators to use an observation (age) along with a factor that was relatively simple to measure (fat-free weight) that could provide an accurate prediction of maximal oxygen uptake. A incremental walking protocol (as outlined by Balke and Ware, 1959) was used in the Hermiston and Faulkner (1971) study. Assessment of physical activity was also included because the response of the physically active subject during exercise differs markedly from that of the physically inactive (Hermiston & Faulkner, 1971). For instance, it is
known that at a given work load, the more active subject has a lower heart rate, extracts a greater percentage of oxygen, ventilates less, and has a lower respiratory exchange ratio than does a more sedentary subject (Âstrand, 1960; Balke & Ware, 1959). Separate groups of subjects were studied based on a habitual physical activity criterion outlined by the authors (Hermiston & Faulkner, 1971) which allowed them to develop individual prediction equations for both "active" and "inactive" groups. The best two equations included the following variables: age, fat-free weight, heart rate, fraction of expired carbon dioxide in expired gas, tidal volume, rate of change in the respiratory exchange ratio (RER), and RER at a submaximal work level. In the "inactive" equation heart rate was replaced in the equation by RER because this group of subjects reached a submaximal RER of 1.1. This RER level of 1.1 was interpreted as an independent measure of physiological strain (maximal effort). Both the Mastropaolo (1970) and Hermiston and Faulkner (1971) studies pointed out that multiple regression could be used with differing test procedures to predict \( \text{VO}_{2\text{max}} \) more accurately than earlier simple regression techniques.

**Perceived exertion as a predictor of \( \text{VO}_{2\text{peak}} \):**

With multiple regression proving to be a valid method of predicting \( \text{VO}_{2\text{max}} \), investigators looked to other variables that could be introduced into the equation to improve or simplify the process. One such variable was rating of perceived exertion. It was proposed by Borg and Noble (1974) that ratings of perceived exertion represent a Gestalt or compilation of total bodily inputs. It is easy to understand that RPE might well be equal to or greater than a single physiological variable in predicting maximal work capacity or maximal oxygen
consumption (Morgan & Borg, 1976). RPE was found to increase in a linear fashion as work intensity increased, as did heart rate. However, in the study of Morgan & Borg (1976) neither heart rate or RPE were found to be superior in predicting maximal work capacity. When combined, heart rate and RPE produced a higher multiple correlation (.73 versus .65) indicating that RPE, either independently or in combination with heart rate, had significant value in predicting maximal work capacity. Furthermore, since work rate and oxygen consumption are linearly related (Mitchell et al., 1958), RPE should add to the prediction of \( \text{VO}_{2\text{max}} \) (Morgan & Borg, 1976).

Studies have been done which have combined most of the successful elements of the aforementioned investigations. Two studies have investigated \( \text{VO}_{2\text{max}} \) prediction using perceived exertion and heart rate as predictor variables. One of the studies used a treadmill protocol (Wilmore et al., 1985) and the other a submaximal cycle ergometry protocol (Wilmore et al., 1986). The Wilmore et al. (1985) treadmill investigation had a sample size that was moderate (N = 42), a moderately high correlation coefficient between predicted and actual \( \text{VO}_{2\text{max}} \) (\( r = .76, \text{SEE} = 4.9 \text{ ml-kg BW}^{-1}\text{-min}^{-1} \)), and was termed "disappointing" by the investigators when compared to studies employing cycle ergometry (Siconolfi et al., 1982). However, the Wilmore et al. (1986) study employing the cycle ergometer protocol provided slightly more encouraging results. The most accurate prediction was obtained using the equation, \( \text{VO}_{2\text{max}} \) (L-min\(^{-1}\)) = 3.49 - 0.0133(HR) - 0.0545(RPE) + 0.0026(power) (in watts). This equation, for the 44 subjects who completed the incremental cycle ergometer test twice, yielded a correlation of .89, (\( \text{SEE} = .291 \)) and a mean difference of 0.004 L-min\(^{-1}\). The equation specified that the data were taken from the third
stage of the test (ninth minute). The corresponding work rate presumably varied with each subject because initial work loads were dependent upon the subjective determination of each subject’s fitness level. Either 29, 59, 88, or 118 watts was chosen for the beginning work rate; subsequent stages represented increases of 29 watts each (Wilmore et al., 1986).

Studies that classified individuals based upon rather vague and subjective determinations of fitness level have been undertaken (Ljunggren & Johansson, 1988; Siconolfi, Lasater, Snow & Carleton, 1985; Wilmore et al., 1986). Studies of this nature intended to improve the prediction accuracy of their regression equations. An example of a study that improved its results by separating subjects into groups based on fitness level was conducted by Ljunggren and Johansson (1988). Instead of attempting to predict VO\textsubscript{2peak}, the authors of the study investigated the predictability of maximal work capacity (W\textsubscript{max}). Heart rate, blood lactate levels, and perceived aches and pain in the legs were used along with ratings of perceived exertion as predictor variables for W\textsubscript{max}. While the purpose of this study was to predict W\textsubscript{max}, VO\textsubscript{2peak} was also determined. The protocol design was similar to other studies using cycle ergometry (Wilmore et al., 1985). Ljunggren and Johansson employed a further-developed version of the Borg scale called the CR-10 scale (Borg, 1982) as their device for measuring perceived exertion. This is a category-ratio scale that allows the comparison between individuals on a ratio level and permits a "maximum" point outside the numerical range to avoid ceiling effects. Substantially high correlations between predicted and actual W\textsubscript{max} were reported. But the importance of the results was somewhat tempered by the fact that moderately high levels of power were required to elicit the best predictions.
The high power levels used in the prediction of $W_{\text{max}}$ could prove to be inappropriately high for some populations. A modest sample size ($N=28$) was used, and the best results were obtained from the "most-fit" sub-group. Separate analysis of which variable was the best predictor led to very modest correlations.

A study that supports the use of age as a prediction variable found high validation correlations ranging from $r = .89$ to $r = .93$ (Kline et al., 1987) when subjects were restricted to homogeneous age groupings (i.e., 30 to 39, 40 to 49, 50 to 59, 60 to 69 years). This is in contrast to the results reported by several others in their attempt to validate a popular $\text{VO}_{2\text{peak}}$ prediction field test (Cooper, 1968) on different or more homogeneous subject groups (Burke, 1976; Doolittle & Bigbee, 1968; Maksud & Coutts, 1971).

Kline and associates (1987) also provided a good summary of the literature concerning the prediction of $\text{VO}_{2\text{max}}$ employing a variety of field and laboratory tests. Based on the results of these studies an adequate goal for standard errors of prediction can be established. $\text{SEE}'s$ which represent a range of between 7 to 14% of the predicted $\text{VO}_{2\text{max}}$ were reported in the studies summarized, with the majority of the values falling in the 10 to 11% range. This would tend to support the acceptance of a standard of 4 to 6 ml·kg BW·min$^{-1}$ as the preferred level of tolerance when error of prediction is discussed.

Non-exercise predictors of $\text{VO}_{2\text{peak}}$

Investigators have also looked at the validity of using non-exercise models to predict $\text{VO}_{2\text{max}}$ from simple demographic and anthropometric variables. In a study conducted on a very large sample ($N=2009$) the zero-order correlations
between measured VO\textsubscript{peak} and the independent variables indicated that percent body fat estimated by skinfolds was the most highly correlated variable \((r = -.68)\), followed by a self-reported activity score \((r = .59)\) (Jackson et al., 1990). These models provided valid estimates of VO\textsubscript{peak} on all subjects tested with the exception of subjects with a VO\textsubscript{peak} \(\geq 55\) ml·kg \text{BW}^{-1}·min\(^{-1}\) (less than 4% of the adult population tested). These non-exercise models were also effective and accurate in estimating VO\textsubscript{peak} in two groups of subjects for which the use of exercise protocols would normally be inappropriate; 59 men who were taking anti-hypertensive medication and 71 men found to have a positive exercise electrocardiogram (ECG). These findings would tend to support the use of the variables chosen in the present investigation in a VO\textsubscript{peak} prediction equation.

In summary, the question of whether VO\textsubscript{max} or VO\textsubscript{peak} can be accurately predicted from submaximal ratings of perceived exertion in combination with other anthropometric and physiological measurements remains to be clearly determined.
CHAPTER III

PROCEDURES AND METHODS

It was the purpose of this investigation to determine the relationship between RPE, HR and percent body fat for the purpose of predicting peak oxygen uptake. This chapter will explain the methods and procedures used in acquiring and analyzing the data that were obtained during this investigation.

Subject selection and testing protocol-

Sixty apparently healthy male subjects and 67 apparently healthy female subjects, all between the ages of 18 and 33 years were recruited primarily from physical education classes at the University of North Texas (UNT). Each subject was screened for contraindications as outlined by the American College of Sports Medicine (ACSM, 1986) via medical history, resting heart rate, resting blood pressure, and resting electrocardiogram. A self-reported physical activity history (Ross & Jackson, 1986, see appendix) was completed by each subject. The time period involved in the physical activity history pertained to the 30 days prior to testing. All subjects were fully informed of the procedures, risks and possible benefits involved in the investigation. Each subject gave voluntary written informed consent (see appendix) before he/she underwent any testing. The complete testing process was approved by the Institutional Review Board for the Protection of Human Subjects at UNT. All subjects had the ratings of perceived exertion scale (see appendix) explained to them and any questions they had were answered before data collection proceeded.
The following measurements were made on an orientation day which preceded the actual test day. Each subject's height was measured using a standard physician's scale (Detecto Scales, Brooklyn, N.Y.) with the subject barefoot. Body mass was measured using a metric scale (Acme Scales, San Leandro, CA.). An estimation of percentage of fat body mass was made employing skinfold calipers (Therapeutic Instruments, Clifton, N.J.). Each one of three sites (chest, abdomen and thigh for men; triceps, suprailium and thigh for women) was measured three to five times. The calculated average for the three sites was summed and the total was entered into an equation to determine body density. The resulting figures were used to estimate fat percentages employing separate equations for male and female subjects according to Jackson and Pollock (1978) and Jackson, Pollock, and Ward (1980) respectively. Anthropometric and physiological descriptions of the subjects are presented in Table 1.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive comparisons of subjects</strong></td>
</tr>
<tr>
<td>Subject Group</td>
</tr>
<tr>
<td>Male (n=60)</td>
</tr>
<tr>
<td>Female (n=67)</td>
</tr>
<tr>
<td>Total (N=127)</td>
</tr>
</tbody>
</table>

**Note.** Values are mean ± standard deviation.

* Physical Activity Score.
Resting heart rate (by palpation of the radial artery for sixty seconds) and resting blood pressure (by auscultation of the antecubital artery) were measured by the primary investigator. A resting 12-lead electrocardiogram was administered employing an ECG monitoring system (Quinton Instruments, Model 633) and pre-gelled disposable bipolar chest electrodes (Contour Electrodes, Model R10). The resulting tracing was screened for contraindications. A written and oral explanation of the RPE scale (See appendix) and how it related to the testing protocol was given to each subject. Each subject was then seated on the electronically braked cycle ergometer (Ergoline, model #800s) and the seat and handlebar positions were adjusted to allow for proper leg extension and comfort. The cycle ergometer operated in a power regulating mode comparing actual work rate with the desired set-point and adjusting the work rate automatically independent of pedalling frequency.

On the actual test day the subject was prepared for a standard ECG (Quinton, model 633), using 5 bipolar chest electrodes, which allowed continuous monitoring of heart rate throughout the test and recovery periods. Subjects were fitted with a standard rubber mouthpiece and noseclips for the purpose of metabolic gas exchange measurements during the test.

The graded exercise test protocol required the subject to maintain a pedalling frequency between 60 and 80 revolutions per minute (rpm). After one minute of load-less pedalling, the subject began three consecutive 4-minute stages of continuous cycling at three different work rates. The work rates for each individual stage were 50, 100, 150 watts for males and 50, 75, and 100 watts for females. Upon completion of the three stages the subjects continued pedalling while the work rate was increased 25 watts (20 watts for females)
each minute. The work rate continued to be increased until volitional fatigue occurred, the required minimum pedalling rate of 60 rpm could not be maintained, or the subjects were close to or approaching their age-adjusted maximum heart rate as determined by the primary investigator. The most common criteria for termination of the test was subjects’ inability to maintain the required pedalling frequency in the face of an increased work rate. Peak VO$_2$ was defined as the highest 15 second average recorded during the test.

Physiological measurements.

During each exercise test, the subjects were required to breath through a mouthpiece connected to a two-way non-rebreathing valve (Hans Rudolph, model 2700). A noseclip was utilized so that partial pressures ($P_{O_2}$ and $P_{CO_2}$) could be measured from the sampling port in the low-resistance valve. Ventilatory and gas exchange responses were measured on a breath-by-breath basis using a computerized system (Medical Graphics, CPX model). The CPX system uses a heated linear pneumotach to measure flow and volume which are read by a shock-mounted variable pressure transducer. Flow and volume are then amplified by a carrier demodulator and sent to a waveform analyzer. Calibration of the pneumotach is performed by the input of known volumes of room air at several different flow rates.

$P_{O_2}$ and $P_{CO_2}$ were measured by rapidly responding O$_2$ and CO$_2$ analyzers which sampled gas at the mouthpiece at a rate of 200 ml·min$^{-1}$. The O$_2$ analyzer utilizes a heated (750°C) zirconia fuel sensor operating linearly from 0 to 100% O$_2$ with a response time of less than 100ms at the sensor. The CO$_2$ analyzer is an infrared absorption analyzer linear from 0 to 10% CO$_2$ with a
response time of less than 100ms at the sensor. With both gas analyzers linear, calibration and zeroing was performed by the input of only one certified gas mixture with known concentrations of $O_2$ and $CO_2$.

Analog outputs from these devices underwent analog to digital conversion via a flow waveform analyzer. On-line computer analysis (Mitsubishi 286 plus, model 300) was used for determination of expired ventilation ($V_E$), $CO_2$ output ($VCO_2$), $VO_2$, RER, and the ventilatory equivalents for $O_2$ and $CO_2$ ($V_E/VO_2$, $V_E/VCO_2$) and were displayed on a color graphics terminal (Mitsubishi, model AUM-1381A) as breath-by-breath data. Hard copy printouts were obtained from an on-line printer (Fujitsu DX-2300).

Statistics.

Correlational analysis and multiple regression analysis were used to determine the relationships between RPE (at 50, 100, and 150 watts for males; 50, 75, and 100 watts for females) HR, percent body fat and $VO_{2\text{PEAK}}$. Relevant descriptive statistics were computed for all independent and dependent variables.
CHAPTER IV

RESULTS

Chapter IV presents the results of this investigation obtained using the statistical methods outlined in Chapter III. Descriptive statistics are presented as the mean values plus or minus the standard deviations of the mean. Correlations and prediction equations are presented plus or minus any standard error of the estimate (± SEE). The central emphasis was to determine the most accurate multiple regression equation which utilized RPE and other predictor variables to predict VO$_{2peak}$.

Descriptive statistics.

Demographic and physical characteristics of the subject group as a whole and by gender were presented in Table 1 of Chapter III on page 20. The values listed in this table are not unexpected and represent a typical "college student" population. The higher VO$_{2peak}$ that is reported for men versus women is obviously expected as is the higher value for body fat percentage reported for women versus men. Presented in Table 2 are peak values that were obtained during the graded exercise test and represent the subjects' maximal effort. The mean values for maximum respiratory exchange ratio (RER) indicated that a maximum effort was obtained from the average subject, with the mean RER climbing over unity to 1.29 (± 0.09). The maximum work rate (in watts) attained during the protocol is described as Wkld$_{max}$. The vast majority of the subjects
terminated the tests due to volitional fatigue. Subjects' predicted maximum heart rate (PHR\textsubscript{max}) was calculated using the commonly employed formula of PHR\textsubscript{max} = 220 - age. Comparing the mean HR\textsubscript{max} (188.1 ± 8.34) with the mean PHR\textsubscript{max} (197.2 ± 3.06) indicates that when maximal levels were reached during the test the average HR\textsubscript{max} was within 5% of the mean predicted maximum heart rate.

TABLE 2

Peak physiological and psychological responses to cycle ergometry

<table>
<thead>
<tr>
<th>Group</th>
<th>VO\textsubscript{2peak} \textsubscript{ml-kg BW\textsuperscript{-1} min\textsuperscript{-1}}</th>
<th>HR\textsubscript{max} \textsubscript{bpm}</th>
<th>RPE\textsubscript{max}</th>
<th>RER\textsubscript{max}</th>
<th>(V_E\textsubscript{max} \textsubscript{l-min\textsuperscript{-1}} )</th>
<th>PHR\textsubscript{max} \textsubscript{a} \textsubscript{bpm}</th>
<th>WLD\textsubscript{max} \textsubscript{watts}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>47.79 ± 9.02</td>
<td>188.22 ± 7.57</td>
<td>19.17 ± 1.01</td>
<td>1.29 ± 0.10</td>
<td>150.3 ± 33.1</td>
<td>196.2 ± 3.2</td>
<td>281.3 ± 53.6</td>
</tr>
<tr>
<td>n=60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fem.</td>
<td>37.07 ± 6.6</td>
<td>188.01 ± 9.03</td>
<td>18.87 ± 0.98</td>
<td>1.29 ± 0.09</td>
<td>93.0 ± 17.9</td>
<td>198.1 ± 2.6</td>
<td>171.9 ± 34.8</td>
</tr>
<tr>
<td>n=67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>42.13 ± 9.47</td>
<td>188.11 ± 8.34</td>
<td>19.01 ± 1.00</td>
<td>1.29 ± 0.09</td>
<td>120.1 ± 38.8</td>
<td>197.2 ± 3.1</td>
<td>223.6 ± 70.6</td>
</tr>
<tr>
<td>n=127</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Values are mean ± standard deviation.

\textsuperscript{a}predicted maximum heart rate using PHR\textsubscript{max} = 220 - age.

\textsuperscript{b}maximum work load achieved reported in watts.

Descriptive statistics for the remaining submaximal variables measured during the test protocol, for both male and female subjects, are presented in Tables 3 and 4 respectively.
### TABLE 3

Submaximal psychological and physiological responses for males

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE @ 50w</td>
<td>8.3</td>
<td>1.8</td>
<td>6.0</td>
<td>12.0</td>
</tr>
<tr>
<td>RPE @ 100w</td>
<td>11.07</td>
<td>2.0</td>
<td>6.0</td>
<td>14.0</td>
</tr>
<tr>
<td>RPE @ 150w</td>
<td>13.62</td>
<td>2.3</td>
<td>8.0</td>
<td>19.0</td>
</tr>
<tr>
<td>HRa @ 50w</td>
<td>104.87</td>
<td>15.1</td>
<td>73.0</td>
<td>139.0</td>
</tr>
<tr>
<td>HR @ 100w</td>
<td>127.87</td>
<td>17.9</td>
<td>98.0</td>
<td>170.0</td>
</tr>
<tr>
<td>HR @ 150w</td>
<td>152.55</td>
<td>18.3</td>
<td>123.0</td>
<td>196.0</td>
</tr>
<tr>
<td>VO2b @ 50w</td>
<td>14.75</td>
<td>2.5</td>
<td>10.6</td>
<td>22.8</td>
</tr>
<tr>
<td>VO2 @ 100w</td>
<td>21.74</td>
<td>2.6</td>
<td>16.1</td>
<td>25.8</td>
</tr>
<tr>
<td>VO2 @ 150w</td>
<td>30.39</td>
<td>4.1</td>
<td>22.8</td>
<td>41.6</td>
</tr>
</tbody>
</table>

aHR in beats per minute.

bVO2 expressed in units of ml·kg BW⁻¹·min⁻¹.

### TABLE 4

Submaximal psychological and physiological responses for females

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE @ 50w</td>
<td>8.64</td>
<td>1.8</td>
<td>1.0</td>
<td>12.0</td>
</tr>
<tr>
<td>RPE @ 75w</td>
<td>11.75</td>
<td>1.6</td>
<td>7.0</td>
<td>15.0</td>
</tr>
<tr>
<td>RPE @ 100w</td>
<td>14.18</td>
<td>2.2</td>
<td>7.0</td>
<td>20.0</td>
</tr>
<tr>
<td>HR @ 50w</td>
<td>123.66</td>
<td>15.1</td>
<td>79.0</td>
<td>164.0</td>
</tr>
<tr>
<td>HRa @ 75w</td>
<td>143.88</td>
<td>16.3</td>
<td>94.0</td>
<td>180.0</td>
</tr>
<tr>
<td>HR @ 100w</td>
<td>163.99</td>
<td>15.9</td>
<td>112.0</td>
<td>194.0</td>
</tr>
<tr>
<td>VO2b @ 50w</td>
<td>16.25</td>
<td>2.0</td>
<td>11.6</td>
<td>21.7</td>
</tr>
<tr>
<td>VO2 @ 75w</td>
<td>21.01</td>
<td>2.8</td>
<td>15.1</td>
<td>27.0</td>
</tr>
<tr>
<td>VO2 @ 100w</td>
<td>26.73</td>
<td>3.6</td>
<td>17.5</td>
<td>34.9</td>
</tr>
</tbody>
</table>

aHR in beats per minute.

bVO2 expressed in units of ml·kg BW⁻¹·min⁻¹.
Correlations.

In order to determine which variable(s) would lead to the best prediction equation, correlations were determined between each measured variable and the criterion variable, \( VO_{2\text{peak}} \). Table 5 contains correlations between each independent variable and \( VO_{2\text{peak}} \).

A listing of correlations for each variable with \( VO_{2\text{peak}} \) grouped by gender follows in Table 6. It provides a better view of which variables provide the best prediction while still being common to both the male and female protocols.

### TABLE 5

**Correlations with \( VO_{2\text{peak}} \)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>( r )</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>-.57</td>
<td>**</td>
</tr>
<tr>
<td>Height</td>
<td>.39</td>
<td>**</td>
</tr>
<tr>
<td>Weight</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.22</td>
<td>*</td>
</tr>
<tr>
<td>% fat</td>
<td>-.75</td>
<td>**</td>
</tr>
<tr>
<td>PAS(^a)</td>
<td>.42</td>
<td>**</td>
</tr>
<tr>
<td>RPE @ 50w</td>
<td>-.24</td>
<td>*</td>
</tr>
<tr>
<td>RPE @ 75w</td>
<td>-.29</td>
<td>*</td>
</tr>
<tr>
<td>RPE @ 100w</td>
<td>-.66</td>
<td>**</td>
</tr>
<tr>
<td>RPE @ 150w</td>
<td>-.54</td>
<td>**</td>
</tr>
<tr>
<td>HR @ 50w</td>
<td>-.58</td>
<td>*</td>
</tr>
<tr>
<td>HR @ 75w</td>
<td>-.37</td>
<td>**</td>
</tr>
<tr>
<td>HR @ 100w</td>
<td>-.67</td>
<td>**</td>
</tr>
<tr>
<td>HR @ 150w</td>
<td>-.57</td>
<td>**</td>
</tr>
</tbody>
</table>

\(^a\)Physical activity score.

* \( p < .01 \). ** \( p < .001 \)
Table 6
Common variable correlations with $VO_{2\text{peak}}$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>.11</td>
<td>-.19</td>
</tr>
<tr>
<td>Weight</td>
<td>-.38</td>
<td>*</td>
</tr>
<tr>
<td>Age</td>
<td>.20</td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td>-.61</td>
<td>**</td>
</tr>
<tr>
<td>PAS*</td>
<td>.45</td>
<td>**</td>
</tr>
<tr>
<td>RPE @ 50w</td>
<td>-.27</td>
<td></td>
</tr>
<tr>
<td>RPE @ 100w</td>
<td>-.51</td>
<td>**</td>
</tr>
<tr>
<td>HR @ 50w</td>
<td>-.42</td>
<td>**</td>
</tr>
<tr>
<td>HR @ 100w</td>
<td>-.52</td>
<td>**</td>
</tr>
</tbody>
</table>

*Physical activity score.

* $p < .01$. ** $p < .001$.

Prediction equations.

Variables were then chosen to construct separate prediction equations for both male and female subjects. While some individual variables among the male and female groups had higher correlations, only those correlations that were highest among shared variables were chosen so as to provide the same choice of variables for both sexes. Since there are no 75 watt data for men or 150 watt data for women, a work rate of 100 watts was chosen. Heart rate (HR100, $r = -.67$) and RPE (RPE100, $r = -.66$) at 100 watts were included in multiple regression to predict $VO_{2\text{peak}}$ for both male and female subjects separately and for all subjects combined. Body fat percentage (PFAT) proved to be the highest correlated variable with $VO_{2\text{peak}}$ among both men and women separately ($r = -.61$), and when the two groups data were combined ($r = -.75$). For males, the multiple correlation ($p<.001$) using PFAT, HR100 and RPE100
as predictors of VO$_{2\text{peak}}$ (ml·kg BW$^{-1}$·min$^{-1}$) was .78 ($SEE = 5.78$). Each predictor contributed ($p<.001$) to the correlation. In women, these same variables yielded a multiple correlation ($p<.001$) of .74 ($SEE = 4.51$) with each predictor contributing ($p<.01$) to the correlation. When data from males and females were combined, the multiple correlation improved. The multiple correlation ($p<.001$) for all subjects using PFAT, HR100 and RPE100 as predictors of VO$_{2\text{peak}}$ (ml·kg BW$^{-1}$·min$^{-1}$) was .83 ($SEE = 5.28$) with each predictor contributing to the correlation ($p<.01$).

The prediction equations that are most accurate in predicting VO$_{2\text{peak}}$ and that yield the above multiple correlations are as follows; for males predicted VO$_{2\text{peak}}$ (ml·kg BW$^{-1}$·min$^{-1}$) = 94.2 - 0.677(PFAT) - 0.16(HR100) - 1.469(RPE100) and for females predicted VO$_{2\text{peak}}$ (ml·kg BW$^{-1}$·min$^{-1}$) = 81.4 - 0.738(PFAT) - 0.084(HR100) - 0.937(RPE100). The prediction equation for all subjects is predicted VO$_{2\text{peak}}$ (ml·kg BW$^{-1}$·min$^{-1}$) = 80.1 - 0.647(PFAT) - 0.087(HR100) - 1.007(RPE100).

Attempts were made to improve the prediction of VO$_{2\text{peak}}$ by using other combinations of variables and the resulting prediction models were thoroughly analyzed. For example, the use of percent body fat and heart rate measured at 100 watts (PFAT-HR), or percent body fat paired with RPE measured at 100 watts (PFAT-RPE) were two other models that provided nearly as accurate a prediction as HR, RPE and PFAT (3VAR) together did. For example, using the PFAT-HR model as the prediction equation yielded a multiple correlation of .81 with a standard error of 5.64 ml·kg BW$^{-1}$·min$^{-1}$. The shared variance in VO$_{2\text{peak}}$ with PFAT and HR100 was 65%. The PFAT-RPE model results in a multiple correlation of .82 and a standard error 5.50 ml·kg BW$^{-1}$·min$^{-1}$. The shared
variance in \( VO_{2\text{peak}} \) with PFAT and RPE100 was 67%. Table 7 presents the three aforementioned models and lists their correlations, coefficients of determination, and standard errors of the estimate for comparison.

Table 7

Comparison of three \( VO_{2\text{peak}} \) prediction models

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>( b )</th>
<th>( r )</th>
<th>( r^2 )</th>
<th>( SEE )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3VAR</td>
<td>( a^a )</td>
<td>80.1037</td>
<td>.8344</td>
<td>.6962</td>
<td>5.2843</td>
</tr>
<tr>
<td></td>
<td>PFAT</td>
<td>-0.6468</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HR100</td>
<td>-0.0873</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RPE100</td>
<td>-1.0067</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFAT-RPE</td>
<td>( a )</td>
<td>74.0067</td>
<td>.8177</td>
<td>.6687</td>
<td>5.4961</td>
</tr>
<tr>
<td></td>
<td>PFAT</td>
<td>-0.7479</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RPE100</td>
<td>-1.3839</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PFAT-HR</td>
<td>( a )</td>
<td>76.6710</td>
<td>.8068</td>
<td>.6510</td>
<td>5.6410</td>
</tr>
<tr>
<td></td>
<td>PFAT</td>
<td>-0.7236</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HR100</td>
<td>-0.1410</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( a^a \)constant in equation.

Figures 1, 2, and 3 are scatter diagrams describing the relations between predicted \( VO_{2\text{peak}} \) and actual \( VO_{2\text{peak}} \) using the 3VAR, PFAT-RPE, and PFAT-HR models respectively.
Figure 1. Relationship between predicted VO\textsubscript{2peak} using 3VAR model and actual VO\textsubscript{2peak}. 
Figure 2. Relationship between predicted $VO_{2\text{peak}}$ using PFAT-RPE model and actual $VO_{2\text{peak}}$. 
Figure 3. Relationship between predicted VO$_{2\text{peak}}$ using PFAT-HR model and actual VO$_{2\text{peak}}$. 
A predictive comparison of the 3VAR model with other models using data from the present investigation was also undertaken. Two models, the Åstrand (1954) single stage and a non-exercise model (N-Ex, Jackson et al., 1990), were chosen as the models for comparison. Out of 127 subject's peak oxygen consumption values, only 12 (all females) had actual VO$_{2peak}$ considered to be unhealthy (less than 31.5, Blair et al., 1989). When the Åstrand model is used with the present data to predict VO$_{2peak}$ ($r = .69$, SEE = 6.85), 8 of the 12 unhealthy VO$_2$ values were detected. In the same situation, when the N-Ex model was chosen ($r = .76$, SEE = 6.19), only 1 of the 12 was detected. When the present 3VAR model is used, 7 of the 12 are detected. Since the prediction from the present investigation is based upon a exercise test (albeit, a submaximal one), it may provide a better method of detecting those individuals who are at risk than a non-exercise model. Table 8 outlines the results of employing the data from the present investigation in the prediction of VO$_{2peak}$. Figures 4 and 5 depict the relationship between predicted and actual VO$_{2peak}$ using the Åstrand and N-Ex models with the data from the present investigation.
Table 8

Comparison of predictions of VO$_{2peak}$ using submaximal exercise and non-exercise models

<table>
<thead>
<tr>
<th>Model</th>
<th>$r$</th>
<th>$r^2$</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Åstrand</td>
<td>.69</td>
<td>.476</td>
<td>6.85</td>
</tr>
<tr>
<td>N-Ex</td>
<td>.76</td>
<td>.577</td>
<td>6.19</td>
</tr>
<tr>
<td>3VAR</td>
<td>.83</td>
<td>.696</td>
<td>5.28</td>
</tr>
</tbody>
</table>

Figure 4. Relationship between predicted VO$_{2peak}$ using Åstrand model and actual VO$_{2peak}$.
Figure 5. Relationship between predicted VO$_{2\text{peak}}$ using N-Ex model and actual VO$_{2\text{peak}}$. 
CHAPTER V

DISCUSSION AND SUMMARY

The purpose of Chapter V is to review and discuss the findings of this study and determine their importance relevant to the results of previous studies. A summary of this investigation and its results is provided. The main finding of this investigation was that ratings of perceived exertion, when used with heart rate and percent body fat at submaximal levels on a cycle ergometer, provided a relatively accurate prediction of peak oxygen consumption. This finding supported the hypothesis outlined in Chapter I. The results are explained and recommendations are stated for further investigation into this area. Conclusions were drawn based on comparisons between this data and that from other studies.

Summary.

Many studies have been conducted in order to determine a satisfactory method of accurately estimating a person's maximal aerobic power. The earliest studies focused on the relationship between heart rate and VO₂ (Åstrand & Ryhming, 1954). The research, based upon the assumption of a linear relationship between heart rate and VO₂, provides the foundation upon which later research is based (Fox, 1973; Glassford et al., 1965; Teräsvirta et al., 1966). The nomogram which is used to facilitate prediction of VO₂ (Åstrand & Ryhming, 1954) has been validated by numerous studies which yield
correlations between predicted and actual VO$_2$ of .65 to .92 (Glassford et al., 1965; Teräslinna et al., 1966).

The assumption of a linear relationship between heart rate and oxygen uptake was questioned by some investigators (Davies, 1968; Rowell et al., 1964). At or near maximum work levels the heart rate-VO$_2$ relationship becomes asymptotic (Davies, 1968; Wyndham et al., 1959) thus leading to underestimations of actual VO$_{2peak}$.

The use of multiple regression generally replaced simple regression as a more accurate technique in the prediction of VO$_{2peak}$. Multiple regression has the possible advantage of reducing fallibility in VO$_{2peak}$ prediction by relying on the use of several different kinds of variables rather than just one physiological variable in the prediction equation (Hermiston & Faulkner, 1971; Mastropaolo, 1970).

Perceived exertion was used successfully in a number of studies when it was added as a variable in the VO$_{2peak}$ prediction equation (Ljunggren & Johansson, 1988; Morgan & Borg, 1976; Wilmore et al., 1986).

The use of non-exercise (N-Ex) models has been investigated to determine if using simple demographic and anthropometric variables in a prediction equation would yield a sufficiently accurate prediction of VO$_{2peak}$ without a corresponding exercise test (Jackson et al., 1990). It was determined that body fat percentage measured by skinfolds along with self-reported activity history were the two variables most highly correlated with actual VO$_{2peak}$. The prediction equations produced multiple correlations with VO$_{2peak}$ in the range of .78 to .82 with standard errors from 5.23 to 5.70 ml·kg BW$^{-1}$·min$^{-1}$ (Jackson et al., 1990).
Review of the literature reveals that a level of tolerance has been accepted related to the error of prediction. Standard errors which represented a range of between 7 to 14% of the predicted VO$_{2peak}$ point to a general acceptance of 4 to 6 ml·kg BW$^{-1}$·min$^{-1}$ (Kline et al., 1987), as an acceptable level of error in the majority of the prediction studies observed.

The purpose of this study was to determine if the use of submaximal RPE and heart rate, in a regression equation along with percent body fat, would provide a valid and accurate prediction of VO$_{2peak}$ during cycle ergometry. The underlying purpose of the study was to develop a simple test that would allow the prediction of peak oxygen uptake within a submaximal setting. A submaximal estimation of VO$_{2peak}$ could be advantageous in that it is often not feasible or desirable to perform a standard maximal stress test to ascertain someone's maximal aerobic power. There are risk factors involved with maximal testing of symptomatic patients and significant time and discomfort are involved in traditional maximal testing protocols. Therefore, it was hoped that a single testing protocol could be developed that would allow submaximal work loads to be used to determine maximal values of oxygen uptake.

The main finding of this study was that perceived exertion, if combined with heart rate and percent body fat, produced a multiple correlation with VO$_{2peak}$ of .83 with a standard error of the estimate of 5.28 ml·kg BW$^{-1}$·min$^{-1}$. This correlation, while not extremely high, is in the middle of the range of correlation values of previous prediction studies (Åstrand & Ryhming, 1954; Hermiston & Faulkner, 1971; Jackson et al., 1990; Ljunggren & Johansson, 1988; Mastropaolo, 1970; Siconolfi et al., 1982; Wilmore et al., 1986). While some studies didn't report a standard error (Doolittle & Bigbee, 1968; Hermiston &
Faulkner, 1971) the standard error of the estimate in the equation reported in the present study (5.28 ml·kg BW\(^{-1}\)·min\(^{-1}\)) is within the range of established standard errors for VO\(_{2\text{peak}}\) prediction studies (Åstrand & Ryhming, 1954; Fox, 1973; Mastropaolo, 1970; Siconolfi et al., 1982). Separate prediction equations utilizing percent body fat and either RPE or heart rate produced multiple correlations of .82 (SEE= 5.6 ml·kg BW\(^{-1}\)·min\(^{-1}\)) and .81 (SEE= 5.5 ml·kg BW\(^{-1}\)·min\(^{-1}\)) respectively.

The results of this study compare favorably with those of similar nature. As mentioned in Chapter IV, a comparison of the prediction accuracy of the present study and the same data used in Åstrand's single stage test produces slightly better results in favor of the 3VAR model. This is true when talking specifically about a comparison of correlations with the 3VAR model having a multiple correlation of .83 (SEE= 5.28) and the Åstrand model .69 (SEE= 6.85). The non-exercise model (Jackson et al., 1990) mentioned in Chapter IV also produced a lower correlation (.76, SEE= 6.19) than the 3VAR model did using the present study's data. Of course in the original study (Jackson et al., 1990) the sample size (N= 2009) was larger and more diverse in age (mean age for males = 43.7) and health (59 men on anti-hypertensive medication, 71 with a positive exercise ECG). The N-Ex model was also cross validated while the 3VAR model was not. One interesting aspect of the three models was their ability to accurately detect VO\(_{2\text{peak}}\) values that represent the low end of the scale, specifically those deemed to be of an unhealthy level, less than 31.5 ml·kg BW\(^{-1}\)·min\(^{-1}\) (Blair et al., 1989). It was pointed out that while it is important to be accurate in predicting peak oxygen capacities, from a clinical viewpoint it may be more important to be able to identify those who have
unhealthy aerobic capacities than to determine who are destined to be excellent endurance athletes. The 3VAR and Åstrand models detect a good portion of the unhealthy values (7 of 12 and 8 of 12 respectively) while the N-Ex model was not as successful (1 of 12). This might support the use of some form of submaximal exercise (rather than no exercise at all) as a variable in the equation if one is trying to accurately predict someone's VO_{2peak} while reaching the goal of ascertaining basic health levels.

A problem that arose in the study that may have confounded the results was that the protocol for women with its resulting progression of 25 watts every four minutes (opposed to the men's increment of 50 watts) resulted in the inability to directly compare the two protocols. In order to develop a single prediction equation for both males and females, only those work loads that were common to both males and females could be used in the equation. This was unfortunate in that correlations with VO_{2peak} for heart rate at both 50 (r = .39) and 75 watts (r = .37) for women were greater than that of 100 watts (r = .36), the highest correlated work load common with men. This disparity in protocols led to a potentially significant difference in the amount of actual exercise time females spent on the ergometer before the same work load of 100 watts was reached (12 minutes for females, 8 minutes for males). Since this difference may have resulted in additional fatigue on the part of the female subjects, in terms of gross minutes of exercise time, it may have skewed their responses given for RPE at 100 watts. This difference in protocols tempers the confidence in the protocols and clouds the wisdom of using 100 watts as the optimum work load in the 3VAR prediction model.
The lack of cross validation in this study is certainly a disappointment but not at all uncommon when compared to other studies (Doolittle & Bigbee, 1968; Hermiston & Faulkner, 1971; Maksud & Coutts, 1971).

Recommendations for further investigation.

Before the present investigation and its resulting prediction model should be looked upon as a viable solution to the problems posed in Chapter 1, a cross validation sample should be chosen and the 3VAR model utilized on this sample to determine the validity of the prediction equation. This would provide a higher level of confidence in the validity of the equations generated by the present investigation. A cross validation sample size should include at least 30 males and 30 females.

Another area that needs to be investigated further is the protocol involved in this investigation. The main problem encountered with this particular protocol was the path involved leading to a common submaximal workload for both male and female subjects. In order to have a more useful VO_{2peak} prediction test, it would be advantageous to have an identical progression of workloads at the submaximal level for both men and women. The problem inherent in the situation is that for the majority of female subjects, the workloads chosen for the male protocol progression and its corresponding percentages of maximum aerobic power, are too high to elicit the same percentage of the female's maximum aerobic power. However, this could be somewhat mitigated if the protocol consisted of a simple warmup followed by a 4 to 5 minute bout of exercise at 100 watts for both sexes. Since the data suggest that for both male and female subjects, 100 watts is a valid work level upon which to predict
VO_{2peak}, then eliminating any unequal amount of exercise before this particular work level may produce the desired results. There might be a problem with the lack of a progressive increase in the work level until the target of 100 watts, although other single stage models have proven to be valid in the past (Åstrand & Ryhming, 1954; Fox, 1973). The one stage protocol should therefore merit consideration for further investigation.

Conclusions.

In light of the results of this study, it is apparent that percent body fat combined with simple exercise responses of ratings of perceived exertion and heart rate provides an accurate prediction of VO_{2peak} in asymptomatic college-aged men and women. Other prediction models using percent fat and heart rate or percent fat and RPE also provide an accurate estimate of VO_{2peak} with this population. These three prediction models all resulted in relatively high correlations with actual VO_{2peak} and acceptable low standard errors.
CONSENT TO ACT AS A HUMAN SUBJECT

Subject's Name (print): ___________________________ Date: ______

1. I hereby volunteer to participate as a subject in the study entitled "Predicting maximal oxygen uptake from ratings of perceived exertion during submaximal cycle ergometry." The purpose of this study is to evaluate the validity of using Ratings of Perceived Exertion (RPE) to predict maximal oxygen uptake ($VO_{2\text{MAX}}$; the criterion method of assessing cardiovascular endurance).

I hereby authorize Eric S. Fairfield and/or assistants as may be selected by him to perform on me the following procedures on an orientation day:

(a) I will complete a medical history form, activity history and have my height and mass measured. I will have my percentage of body fat estimated by the use of skinfold calipers. If no contraindications are revealed by this;

(b) I will have my resting heart rate (by palpation) and resting blood pressure (auscultation method) taken. If these are within acceptable limits (HR: 50 to 90 bpm; BP: 100/50 to 140/90 mm Hg);
(c) to have a resting 12-lead electrocardiogram (EKG) administered. If no abnormalities are present, data collection will proceed.

(d) I will be prepared for the testing protocol by having an explanation of RPE provided. I will then be familiarized with the cycle ergometer and the seat height will be adjusted to allow me proper leg extension. I will pedal on the bike for approximately six minutes at very light work loads to become familiar with the test protocol.

2. (a) On the actual test day I understand I will have the EKG leads applied to continuously monitor heart rate during and after the test. An EKG recording will be made from the V5 lead.

(b) I will perform the testing protocol one time which consists of:

i) performing 3 consecutive 4-minute stages of continuous cycling at three different work rates. The work rates will be different for male and female subjects with 50, 100, and 150 watts for males and 50, 75, and 100 watts for females.

ii) upon completion of these 3 stages I will continue pedalling while the work rate is increased 25 watts each minute for males and 20 watts each minute for females. I will cycle until I feel I’m unable to continue, until I can’t maintain the required pedalling rate, or until the primary investigator terminates the test. (I understand that this VO_{2\text{MAX}} test may take about 15-25 minutes).
iii) at the end of each stage and at regular intervals, I will point to a number on the RPE chart which is associated with a word cue reflecting my perceived level of effort.

iv) I understand that to determine my rate of oxygen consumption, expired air will be continuously analyzed by the Medical Graphics model 2001. I understand that this monitoring requires breathing through a mouthpiece and that my nose be pinched shut with a nose-clip throughout the test.

3. (a) The above procedures outlined in paragraphs 1 and 2 have been explained to me by Eric S. Fairfield.

(b) I understand these procedures may involve the following risks and discomforts: temporary muscle pain and soreness is expected. There is the possibility of abnormal changes in my heart beat or blood pressure, or even heart attack during the test. However, I understand that my EKG will be monitored during testing, and that I can terminate the test at any time at my discretion.

(c) I have been advised that the following benefits will be derived from my participation in this study: aside from the education benefit of learning about my fitness level, there are no direct benefits to me.

(d) I understand that Eric S. Fairfield and/or assistants as may be selected by him will answer any inquiries that I may have at any time.
concerning these procedures and/or investigations. Eric S. Fairfield will be available at any time to answer questions. His phone number is (817) 656-1300.

(e) I understand that all data concerning myself will be kept confidential and available only upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

(f) I understand that there is no monetary compensation for my participation in this study.

(g) I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided. Medical treatment will be available at the University Health Center located at the intersection of Chestnut Avenue and Avenue C. In the event of a medical emergency, the laboratory has an outside telephone line to the City of Denton emergency services.

(h) I understand that I may terminate participation in this study at any time without prejudice to future care or course grade, except as provided herein, and owing to the specific nature of this study, the investigator may terminate the procedures and/or investigations at any time.
(i) I understand my permission to participate in this study is voluntary. I am free to deny consent if I so desire.

(j) I understand that I may contact the chairperson of the Kinesiology Department's Committee on the Use of Human Subjects in Research, Dr. Bob Weinberg (Physical Education Building, Room 112, 817-565-3430) regarding matters concerning my participation in this study or if I feel that there is infringement on my rights.

Subject’s Signature:__________________________________________

Witness:__________________________________________ Date:__/__/___
RATINGS OF PERCEIVED EXERTION

6
7 VERY, VERY LIGHT
8
9 VERY LIGHT
10
11 FAIRLY LIGHT
12
13 SOMewhat HARD
14
15 HARD
16
17 VERY HARD
18
19 VERY, VERY HARD
20
RATINGS OF PERCEIVED EXERTION

You will be cycling on a cycle ergometer while we monitor your rate of oxygen uptake and your heart rate. We will also ask you to estimate how hard you feel you are working.

By perceived exertion we mean the total amount of exertion and physical fatigue combining all sensations and feelings of physical stress, effort, and fatigue. Don't concern yourself with any one factor such as leg discomfort or shortness of breath, but try to concentrate on your total inner feeling of exertion. Try to estimate as honestly and as objectively as possible. Don't underestimate the degree of exertion you feel, but don't overestimate it either. Just try to estimate as accurately as possible. When you are asked to rate your work you should do so by giving the numerical value, on the scale in front of you, which indicates your evaluation of your perceived exertion at that moment.
CODE FOR PHYSICAL ACTIVITY*

Use the appropriate number (0 to 7) which best describes your general ACTIVITY LEVEL for the PREVIOUS MONTH.

Do Not participate regularly in programmed recreation, sport or heavy physical activity.

0 - Avoid walking or exertion, e.g., always use elevator, drive whenever possible instead of walking.

1 - Walk for pleasure, routinely use stairs, occasionally exercise sufficiently to cause heavy breathing or perspiration.

Participated regularly in recreation or work requiring modest physical activity, such as golf, horseback riding, calisthenics, gymnastics, table tennis, bowling, weight lifting, yard work.

2 - 10 to 60 minutes per week.

3 - Over one hour per week.

Participated regularly in heavy physical exercise, e.g., running or jogging, swimming, cycling, rowing, skipping rope, running in place, or engaging in vigorous aerobic activity type exercise such as tennis, basketball of handball.

4 - Run less than one mile per week or spend less than 30 minutes per week in comparable physical activity.

5 - Run 1 to 5 miles per week or spend 30 to 60 minutes per week in comparable physical activity.

6 - Run 5 to 10 miles per week or spend 1 to 3 hours per week in comparable physical activity.

7 - Run over 10 miles per week or spend over 3 hours per week in comparable physical activity.

*Developed of use at NASA/Johnson Space Center, Houston, Texas.
REFERENCES


