



Validation of the 1-mile walking test in young adults at maximal and submaximal walking intensities
by Christopher Paul Keller

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Health and Human Development

Montana State University

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Abstract:

The purposes of this study were (a) to determine whether the generalized equations developed by Kline et al. (1987) and Dolgener et al. (1994) for the one-mile walk test provide accurate estimates of maximal oxygen uptake ($\text{VO}_{2\text{max}}$) in young adults and (b) to determine whether submaximal walking intensities could provide equally accurate estimates from the respective equations. $\text{VO}_{2\text{max}}$ was measured using a treadmill graded exercise test on 40 volunteers (20 males, 20 females) between the ages of 18 and 29 years. On three subsequent visits, one-mile walk tests were performed at maximal, moderate and low walking intensities. Two-factor repeated measures analysis of variance (ANOVA) comparisons were used to examine the relationships between estimated and measured $\text{VO}_{2\text{max}}$ values. Under maximal intensity walking conditions, the estimates of $\text{VO}_{2\text{max}}$ from the Kline equation ($50.10 + 6.84 \text{ ml.kg}^{-1}.\text{min}^{-1}$) and from the Dolgener equation ($47.20 + 5.14 \text{ ml.kg}^{-1}.\text{min}^{-1}$) were significantly less than actual $\text{VO}_{2\text{max}}$ ($53.29 + 8.50 \text{ ml.kg}^{-1}.\text{min}^{-1}$) ($P < 0.01$). Systematic underestimations were also found with the submaximal walking intensities ($P < 0.01$). Estimations of $\text{VO}_{2\text{max}}$ were considered to be acceptable if within $4.50 \text{ ml.kg}^{-1}.\text{min}^{-1}$. Thirty-five to fifty percent of the predictions from the Kline equation were acceptable, while approximately thirty percent of the Dolgener predictions were acceptable. The $\text{VO}_{2\text{MAX}}$ values of the subjects in the current study were above those observed by Kline et al. (1987) ($36.5 \pm 10.6 \text{ ml.kg}^{-1}.\text{min}^{-1}$) and by Dolgener et al. (1994) ($40.3 \pm 6.49 \text{ ml.kg}^{-1}.\text{min}^{-1}$). Regression analysis was performed to adjust for these differences. Following regression analysis, the estimations from the Kline equation for maximal and moderate intensity tests were no longer significantly different from the adjusted $\text{VO}_{2\text{max}}$ ($P = 0.9673$ and $P = 0.5034$). However, regression analysis could not account for differences from the low intensity walk test ($P = 0.045$). For the Dolgener equation regression analysis did not account for difference between actual and predicted $\text{VO}_{2\text{max}}$ ($P < 0.001$). The findings of this study show neither the Kline nor the Dolgener equations provide acceptable estimates of $\text{VO}_{2\text{max}}$ in young adults. Following adjustments for fitness level, the Kline equation was able to provide acceptable estimates of $\text{VO}_{2\text{max}}$ at maximal and moderate walking intensities.

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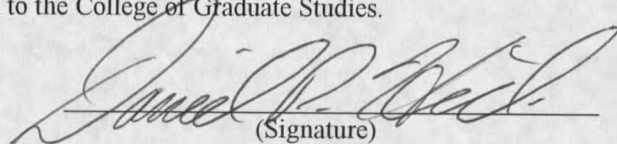
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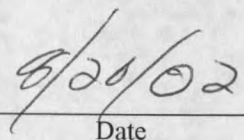
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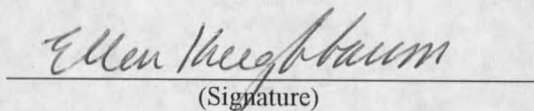
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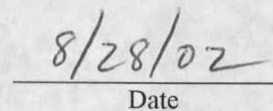

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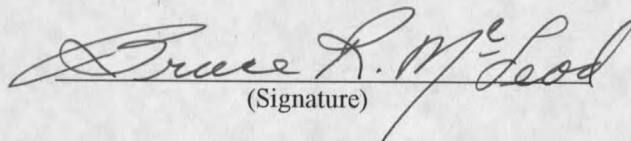
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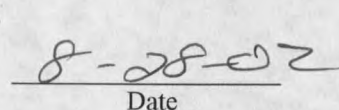

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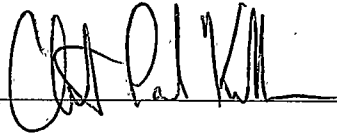

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ABSTRACT

The purposes of this study were (a) to determine whether the generalized equations developed by Kline et al. (1987) and Dolgener et al. (1994) for the one-mile walk test provide accurate estimates of maximal oxygen uptake ($\dot{V}O_{2MAX}$) in young adults and (b) to determine whether submaximal walking intensities could provide equally accurate estimates from the respective equations. $\dot{V}O_{2MAX}$ was measured using a treadmill graded exercise test on 40 volunteers (20 males, 20 females) between the ages of 18 and 29 years. On the subsequent visits, one-mile walk tests were performed at maximal, moderate and low walking intensities. Two-factor repeated measures analysis of variance (ANOVA) comparisons were used to examine the relationships between estimated and measured $\dot{V}O_{2MAX}$ values. Under maximal intensity walking conditions, the estimates of $\dot{V}O_{2MAX}$ from the Kline equation ($50.10 \pm 6.84 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and from the Dolgener equation ($47.20 \pm 5.14 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) were significantly less than actual $\dot{V}O_{2MAX}$ ($53.29 \pm 8.50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) ($P < 0.01$). Systematic underestimations were also found with the submaximal walking intensities ($P < 0.01$). Estimations of $\dot{V}O_{2MAX}$ were considered to be acceptable if within $4.50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Thirty-five to fifty percent of the predictions from the Kline equation were acceptable, while approximately thirty percent of the Dolgener predictions were acceptable. The $\dot{V}O_{2MAX}$ values of the subjects in the current study were above those observed by Kline et al. (1987) ($36.5 \pm 10.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and by Dolgener et al. (1994) ($40.3 \pm 6.49 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). Regression analysis was performed to adjust for these differences. Following regression analysis, the estimations from the Kline equation for maximal and moderate intensity tests were no longer significantly different from the adjusted $\dot{V}O_{2MAX}$ ($P = 0.9673$ and $P = 0.5034$). However, regression analysis could not account for differences from the low intensity walk test ($P = 0.045$). For the Dolgener equation regression analysis did not account for difference between actual and predicted $\dot{V}O_{2MAX}$ ($P < 0.01$). The findings of this study show neither the Kline nor the Dolgener equations provide acceptable estimates of $\dot{V}O_{2MAX}$ in young adults. Following adjustments for fitness level, the Kline equation was able to provide acceptable estimates of $\dot{V}O_{2MAX}$ at maximal and moderate walking intensities.

CHAPTER ONE

INTRODUCTION

Background

Heart disease and cancer are the two leading causes of death each year in the United States. According to the Centers for Disease Control and Prevention these chronic diseases account for greater than half of the annual mortality rate (ACSM, 2001). A sedentary lifestyle has been found to increase one's risk for both Coronary Artery Disease and certain types of cancer. Regular physical activity is associated with positive changes in several risk factors including blood pressure and body composition. Other benefits include; the ability to work at greater intensities prior to the onset of disease symptoms, a lower heart rate at submaximal workloads, and an increased work intensity at lactate threshold (ACSM, 2001). An increase in physical activity is associated with an improved quality and duration of life.

Since the early 1900's a number of methods have been developed to monitor cardiorespiratory health. The Blood Ptosis Test, developed by C. Ward Crampton in 1905, was the first to test cardiovascular function. The test consists of monitoring changes in heart rate and blood pressure after rising from a supine position. In the 1920's, E.C. Schneider developed a test that involves measuring heart rate and blood pressure while sitting and standing, along with the ability restore resting values following a bout of exercise. This test was later used to evaluate the physical condition of pilots during World War II. In 1931, W.W. Tuttle developed the Tuttle Pulse-Ratio Test, which provides a measure of endurance and aerobic training from block stepping (Safrit and Wood, 1995). While many researchers in the early 1900's concentrated on the use of blood pressure and heart rate to evaluate cardiorespiratory function, Archibald V. Hill, now considered the "father" of exercise physiology, supported the use of maximal oxygen uptake ($\dot{V}O_{2MAX}$) (Robergs and Roberts, 1997).

Per-Olaf Astrand and Kaare Rodahl, authors of one of the most influential textbooks in exercise physiology, showed support for $\dot{V}O_{2MAX}$ by writing:

During prolonged heavy physical work, the individual's performance capacity largely depends upon his ability to take up, transport, and deliver oxygen to working muscle. Subsequently, the maximal oxygen uptake is probably the best laboratory measure of a person's physical fitness, providing the definition of physical fitness is restricted to the capacity of the individual for prolonged heavy work. (Astrand & Rodahl 1970, p. 314)

Today $\dot{V}O_{2MAX}$ is considered to be the best single measure of cardiorespiratory function.

Although there is much support for the use of $\dot{V}O_{2MAX}$ in the evaluation of aerobic fitness, the measurement of $\dot{V}O_{2MAX}$ requires expensive equipment, a high degree of subject motivation, and trained technicians. Thus, it is an impractical measure for large groups of people. However, a number of tests have been developed to estimate $\dot{V}O_{2MAX}$ using biking, walking, running, and bench stepping. Unfortunately, tests developed using treadmills and bicycle ergometers require the equipment to be calibrated. This is rarely seen outside of the laboratory. Bench stepping protocols require benches of exactly the same height as those in the original validation study. Bench stepping protocols are further limited in their application due to the disadvantage they impose on individuals with shorter leg lengths. These individuals, in terms relative to their body height, are required to take larger steps. While most tests have a number of inherent limitations, over-ground walking and running tests provide $\dot{V}O_{2MAX}$ estimations with a minimal number of limitations. In fact, many of these tests require little more than a means to accurately measure heart rate.

The Rockport Fitness Walking Test (RFWT) is a one-mile walking test, which provides an estimation of $\dot{V}O_{2MAX}$ without the use of expensive equipment. Kline et al. (1987) validated and cross-validated the RFWT using 343 healthy adults (165 males, 178 females) between the ages of 30 and 69 years. Subjects were instructed to walk for one mile at the fastest speed that they could maintain (WS_{MAX}). A multiple regression equation was developed to estimate the person's $\dot{V}O_{2MAX}$ (in units of $ml \cdot kg^{-1} \cdot min^{-1}$) from the subject's age, body weight, gender, average heart rate for the last two minutes of the walk (HR_{AVG}), and time to complete the walk. The generalized equation provided estimates of $\dot{V}O_{2MAX}$ that correlated closely with the measured values ($r = 0.88$) and accounted for 77% of the variability among subjects. The cross-validation, which used 169 of the subjects, resulted in an identical correlation

coefficient ($r = 0.88$) and thus also accounted for 77% of the variability in the subjects' $\dot{V}O_{2MAX}$.

Although Kline et al. (1987) validated the RFWT on a group with a wide age range, it did not include adults younger than 30 years of age. Coleman et al. (1987) tested the validity of the RFWT on a group of 90 volunteers (40 males, 50 females) between the ages of 20 and 29. The generalized equation was found to accurately estimate $\dot{V}O_{2MAX}$ for these young adults. However, Dolgener et al. (1994) found the generalized equation to systematically overestimate $\dot{V}O_{2MAX}$ for young adults. An alternate equation was developed by Dolgener et al. (1994) to provide for estimates of $\dot{V}O_{2MAX}$ for college-aged individuals. George et al. (1998) performed a cross-validation study to determine whether the equation developed by Kline et al. (1987) or by Dolgener et al. (1994) provided more accurate estimates of $\dot{V}O_{2MAX}$ for individuals between 18 and 29 years of age. George et al. (1998) found the generalized equation developed by Kline et al. (1987) to overestimate $\dot{V}O_{2MAX}$, whereas the generalized equation developed by Dolgener et al. (1994) provided acceptable estimates. Clearly, the results from these studies are conflicting.

Some of the differences between these studies may help to explain the results. For example, the method by which heart rate was determined varied from one study to another. Both Dolgener et al. (1994) and George et al. (1998) used post-exercise heart rate to predict $\dot{V}O_{2MAX}$. However, Kline et al. (1987) and Coleman et al. (1987) used the average heart rate during the last two minutes of the walk (HR_{AVG}) to estimate $\dot{V}O_{2MAX}$. Undoubtedly, individuals will speed up during the last portion of a one-mile walk, resulting in a rise in heart rate and possibly a substantial difference between these values. Wilkie et al. (1987) found that using recovery heart rate rather than HR_{AVG} resulted in accurate estimates for males but slightly overestimated $\dot{V}O_{2MAX}$ values for females. Although the technique by which heart rate values are determined may not alone significantly alter the estimates, it is possible that a combination of factors may have resulted in the differences between the results of the studies. Differences between the subjects' fitness levels, subjects' ages, and equipment used to measure $\dot{V}O_{2MAX}$ may also help to account for the differences seen in the results. Obviously, research is needed to determine whether the Kline equation or the Dolgener equation provides for better estimates of maximal oxygen uptake for adults younger than 30 years of age.

The Rockport Fitness Walking Test requires individuals to walk at the fastest steady pace that can be maintained (WS_{MAX}). However, individuals are often uncomfortable walking at a maximal pace and

may experience calf and shin pain during the walk. Thus a question that arises is whether the predictive accuracy of the RFWT is maintained at intensities lower than WS_{MAX} (WS_{SUBMAX}). It has been suggested that the RFWT should maintain its predictive accuracy at WS_{SUBMAX} as long as the heart rate is within the near linear heart rate- $\dot{V}O_2$ relationship (George et al., 1998). According to Golding et al. (1989), the near linear heart rate- $\dot{V}O_2$ relationship begins at approximately 110 beats per minute (bpm). Support for the use of low intensity walking paces was shown when George et al. (1998) found the Dolgener equation to provide acceptable estimates of $\dot{V}O_{2MAX}$ when the subjects used "brisk" rather than maximal walking paces. In fact, 8 subjects in this study exhibited heart rates below 110 bpm, yet $\dot{V}O_{2MAX}$ was still predicted accurately. Further research will help to answer the questions as to whether the accuracy of the RFWT is maintained at lower walking intensities and at which point it loses its predictive accuracy.

Statement of Purpose

The primary purpose of this study was to determine whether either the Kline or the Dolgener generalized equations provide better estimates of $\dot{V}O_{2MAX}$ for individuals between 18 and 29 years of age. The secondary purpose was to determine whether the RFWT maintains its predictive accuracy at submaximal walking intensities.

Significance of the Study

The results from this study will help to identify which generalized equation for the RFWT is most appropriate for individuals between 18 and 29 years of age. In addition, the results may support the use of the RFWT on a larger group of people by eliminating the need to walk at a maximal intensity.

Hypothesis

For the primary purpose of the study, the null hypothesis was that neither the Kline nor the Dolgener generalized equation would provide accurate estimates for $\dot{V}O_{2MAX}$. The alternative hypothesis was that one or both of the generalized equations would provide accurate estimates of $\dot{V}O_{2MAX}$.

Primary Hypothesis

$$H_o : \mu_M \neq \mu_K \neq \mu_D$$

$$H_a : \mu_M \text{ will equal either or both } \mu_K \text{ and } \mu_D$$

Where: μ_M is the mean measured $\dot{V}O_{2MAX}$ value

μ_K is the mean estimate for $\dot{V}O_{2MAX}$ using the Kline equation

μ_D is the mean estimate for $\dot{V}O_{2MAX}$ using the Dolgener equation

For the secondary purpose of the study, the null hypothesis was that neither of the submaximal walking intensities would provide accurate estimates of $\dot{V}O_{2MAX}$. The alternative hypothesis was that at least one of the submaximal walking intensities would provide an accurate estimate of $\dot{V}O_{2MAX}$.

Secondary Hypothesis

$$H_o : \mu_1 \neq \mu_2 \neq \mu_3$$

$$H_a : \mu_1 \text{ will equal either or both } \mu_2 \text{ and } \mu_3$$

Where: μ_1 is the mean estimated $\dot{V}O_{2MAX}$ value when walking at a maximal intensity

μ_2 and μ_3 are the mean estimates for $\dot{V}O_{2MAX}$ when walking at submaximal intensities

Limitations

1. Environmental conditions of the Shroyer Gym track varied between the subject's visits.
2. Day to day fluctuations in heart rate could have an effect on the pace required to perform the submaximal walking tests.
3. The subjects' unfamiliarity with maximally paced walking could potentially effect the walking time and heart rate measurements for the maximally paced walking test.

Delimitations

1. The scope of this study was delimited to adults between 18 and 29 years of age in the Bozeman, Montana area.
2. Due to health related contraindications to maximal intensity exercise, the study was delimited to "low risk individuals" (as defined by ACSM's Guidelines for Exercise Testing and Prescription, 6th edition, 2000).

Operational Definitions

Age Predicted Maximal Heart Rate:	220 minus current age in years
Heart Rate Reserve (HRR):	Maximum heart rate minus resting heart rate
Intraclass correlation coefficient (R_{xx})	A correlation coefficient that estimates test variability
Maximal Oxygen Uptake ($\dot{V}O_{2MAX}$):	The highest rate of oxygen transport and use that can be achieved at maximal physical exertion.
Pearson product-moment Correlation (r)	An estimate of the validity of a test

Operational Definitions (Continued)

Respiratory Exchange Ratio (RER):	The ratio of CO ₂ produced to the volume of O ₂ consumed during resting or steady state exercise conditions.
Standard Deviation	A measure of the variability or spread, of a set of scores around the mean
Standard Error	A value indicating the amount of variation to expect in the mean if the subjects were tested again
Standard Error of Estimate	A value indicating the amount of error to expect in a predicted score
Standard Error of Measurement	The amount of error expected in a measured score

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Maximal oxygen uptake is defined as the highest rate of oxygen transport and use that can be achieved at maximal physical exertion (ACSM, 2001). Maximal oxygen uptake ($\dot{V}O_{2MAX}$) is generally reported in units of liters per minute ($l \cdot min^{-1}$) or milliliters per kilogram of body mass per minute ($ml \cdot kg^{-1} \cdot min^{-1}$). Values for college aged males and females usually range from 44 to 50 $ml \cdot kg^{-1} \cdot min^{-1}$ and 38 to 42 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. Other than body mass and the related differences in muscle mass, factors influencing $\dot{V}O_{2MAX}$ include age, gender, and training. Age related changes are usually attributed to changes in muscle mass and physical activity. For example, an elderly person is likely to have less muscle, thus reducing the maximal rate at which oxygen can be consumed. Furthermore, lower physical activity levels are likely to be accompanied by reductions in mitochondrial and capillary densities. Thus, further restricting the ability to take up and use oxygen. Gender differences are most often attributed to differences in muscle mass and hematocrit levels. On average, females tend to have less muscle mass to consume oxygen. Furthermore, females tend to have lower hematocrit levels. The lower red blood cell levels may further act to limit a female's $\dot{V}O_{2MAX}$. The type of training and daily activities that a person participates in have an influence on the results of $\dot{V}O_{2MAX}$ testing (Hermansen and Saltin, 1969; McArdle et al., 1978; Magel et al., 1974). McArdle et al. (1978) tested 19 subjects before and after ten weeks of interval-run training and found treadmill $\dot{V}O_{2MAX}$ measures to improve significantly, whereas the swimming $\dot{V}O_{2MAX}$ measures did not.

There are two classic theories that have been used to identify the factors limiting an individual's $\dot{V}O_{2MAX}$. The first, the central limit theory, assumes that factors related to the cardiovascular and pulmonary systems are responsible for the plateau in oxygen uptake (Robergs and Roberts, 1997). Examples of central limitations include the ability of the lungs to transfer oxygen to the blood, hematocrit

levels, and the maximum cardiac output. The second theory attributes the leveling of oxygen consumption to limitations at the level of the muscle (Robergs and Roberts, 1997). Mitochondrial and capillary densities would be considered to be peripheral limitations. Although both of these schools of thought have been valuable in helping to identify possible limitations, neither is now considered to be the single correct theory.

$\dot{V}O_{2MAX}$ Measurement

The measurement of $\dot{V}O_{2MAX}$ requires the use of expensive equipment, which is capable of determining not only the volume of gas exhaled, but also the oxygen and carbon dioxide concentrations. Prior to testing, a number of criteria are usually identified in order to assist the researcher in establishing the $\dot{V}O_{2MAX}$. These criteria often include a respiratory exchange ratio (RER) ≥ 1.10 , a rating of perceived exertion (RPE) ≥ 9 , heart rate no more than 15 beats below the age predicted maximum (220-age), and a leveling of oxygen consumption despite an increase in workload. Taylor et al. (1955) originally defined the last criterion to identify a maximal oxygen uptake. However, often a plateau, in oxygen consumption despite an increase in workload, is not seen. For this reason, researchers have searched for other objective measures to identify an individual's $\dot{V}O_{2MAX}$. The single largest value ($\dot{V}O_{2PEAK}$) is used in the absence of this plateau. Unfortunately, aberrant measures could result in inaccurate $\dot{V}O_{2MAX}$ values. Therefore, caution is needed when basing the result on a peak value.

Table 1 gives some examples of treadmill protocols developed for the measurement of $\dot{V}O_{2MAX}$. When choosing a $\dot{V}O_{2MAX}$ test protocol, the researcher should choose a modality with which the subjects are familiar. Modalities that require specific skills or extensive training are usually inappropriate. Furthermore, the stages of the protocol should "be long enough to permit cardiovascular compensation for the increased workload while not inducing secondary alterations due to local fatigue" (Egger and Finch, 1988, page 355). Some tests, such as the Taylor protocol listed in Table 1, include periods of rest between stages that help to prevent local fatigue and overheating. In contrast, the Bruce and Balke protocols are continuous and thus include no rest periods. Furthermore, the stages of the Balke protocol are only one

minute in duration. At high levels of physical exertion, this may not be enough time for the subject to reach a steady-state.

Table 1. Test protocols for measuring $\dot{V}O_{2MAX}$.

Protocol	Initial speed	Initial grade	Stage duration	Rest period	Description
Balke	3.3 mph	2%	1 minute	None	Constant speed with a 1% increase in grade every minute
Bruce	1.7 mph	10%	3 minutes	None	Speed and grade change every 3 minutes * (1.7, 10; 2.5, 12; 3.4, 14; 4.2, 16; 5.0, 18; 5.5, 20; then + 0.5 mph and +2% grade each stage thereafter)
Taylor	3.5 mph	10%	3 minutes	30 minutes	After the first stage, speed is fixed at 7 mph and grade is lowered to 0%. For the following stages grade is increased by 2.5% every 3 minutes

* values in parentheses are (speed, grade; next stage speed, next stage grade; ...)

$\dot{V}O_{2MAX}$ Estimation

Although direct measurement is the most accurate means of assessing $\dot{V}O_{2MAX}$, it requires expensive equipment, trained technicians, a maximal effort from the participant, and a considerable time commitment. For these reasons, test protocols have been developed to estimate $\dot{V}O_{2MAX}$.

A trend found among these test protocols is the use of heart rate to predict $\dot{V}O_{2MAX}$. The relationship between heart rate and oxygen uptake (HR- $\dot{V}O_2$ relationship) becomes nearly linear above approximately 110 beats per minute (Golding et al., 1989). It is likely that this relationship is why heart rate is used in so many prediction equations. However, heart rate during submaximal exercise can be influenced by a number of factors including: dehydration, prolonged heavy exercise prior to testing, environmental conditions, fever, and the use of caffeine, alcohol or tobacco (ACSM, 2001). Many other predictive variables are also related to the HR- $\dot{V}O_2$ relationship. For example, body mass is related to the

work performed by an individual during weight bearing exercises. The time taken to walk or run a given distance is related to the rate at which the work is being performed and thus the rate of oxygen uptake. In fact, every variable in these equations can in some manner be related to the HR- $\dot{V}O_2$ relationship.

A researcher choosing a test to estimate maximal oxygen uptake should consider not only the testing modality, but also consider the group used to validate the test. Ideally, the characteristics of the subjects to be tested will match those of the validation sample. A simple means to classify these tests is by their modality.

Characteristics of a Good Prediction Equation

A good prediction equation can be identified using several characteristics. A high Pearson-moment correlation (r) between measured and predicted $\dot{V}O_{2MAX}$ values is desirable. If regression analysis was used to develop the equation, then a high R value will show that the independent variables account for most of the variability found in the measured $\dot{V}O_{2MAX}$ values. Other statistical characteristics to consider are the total error (E), SEE, and bias. Preferably, the total error (E) and SEE values will be small. Ideally, these two values will also equal one another, which indicates that the equation does not have bias. A large sample group and cross-validation will help to ensure dissimilar individuals are taken into account. Equations developed using both genders and a wide age range of individuals allow for their use on a large population. Lastly, a wide range of aerobic capacities in the validation study provides for the equation's use on a large population.

Step Test Protocols

Examples of stepping tests developed to predict $\dot{V}O_{2MAX}$ are listed in Table 2. As mentioned earlier, the height of the step should exactly match the step height used in the original validation study. Even with this taken into consideration, subjects with relatively short leg lengths are at a disadvantage due to the larger relative height which they are required to raise their bodies. Many of the tests listed in Table 2 had low Pearson product-moment correlations (r) between predicted and measured $\dot{V}O_{2MAX}$ for the validation group. Furthermore, several of the tests require the use of expensive equipment such as a

metabolic cart (Astrand and Ryhming, 1954; Jette et al., 1976). The only study that was validated using both male and female subjects was by Jette et al. (1976). Thus many stepping protocols are limited by gender specificity and/or predictive accuracy.

Cycle Ergometer Test Protocols

Examples of cycle ergometer test protocols for predicting $\dot{V}O_{2MAX}$ are listed in Table 3. The relatively safe positioning of the subject during a cycling test is one advantage these protocols have over most others. Wherein treadmill and stepping tests the subject could easily fall, in a cycle ergometer protocol the subject is already being supported by the cycle ergometer. The cycling test described by Astrand and Ryhming (1954) is still used today to predict $\dot{V}O_{2MAX}$. However, an age correction factor is now included (ACSM, 2000). Siconolfi et al. (1982) improved the predictive accuracy of the Astrand-Ryhming nomogram by developing an equation to adjust for age. This equation was shown to provide more accurate estimates of $\dot{V}O_{2MAX}$ in comparison to those from using the age-corrected Astrand-Ryhming test. However, it is the age-corrected Astrand-Ryhming test that is supported by the American College of Sports Medicine. Although the test developed by Siconolfi et al. (1982) provides a means to accurately estimate $\dot{V}O_{2MAX}$, it is still limited by the inherent problems of cycling protocols. Cycling protocols require the use of an ergometer that is calibrated, which is rarely seen outside of research settings. Therefore, if performed within a health and fitness center, an unknown amount of error is added to that of the test.

Treadmill Test Protocols

Protocols using treadmill walking to estimate $\dot{V}O_{2MAX}$ are listed in Table 4. Table 5 lists test protocols that use treadmill jogging or running to estimate $\dot{V}O_{2MAX}$. Several of the researchers listed (Bonen et al., 1979; Hermiston and Faulkner, 1971; and Metz and Alexander, 1971) developed protocols that require the use of a metabolic cart. In these tests, the metabolic cart is used to measure the subject's submaximal oxygen uptake ($\dot{V}O_2$), expired carbon dioxide (CO_2), or respiratory exchange ratio (RER). Furthermore, several protocols were validated using only males (Bonen et al., 1979; Coleman, 1976; Hermiston and Faulkner, 1971; and Metz and Alexander, 1971). The remaining protocols, which were

developed using both genders and do not require expensive equipment, provide $\dot{V}O_{2MAX}$ estimations with high correlations to actual $\dot{V}O_{2MAX}$ (r between 0.84 and 0.96) (Ebbeling et al., 1991; George et al., 1993a; Latin and Elias, 1993; and Widrick et al., 1992). Several of these treadmill test protocols (George et al., 1993 a; Ebbeling et al., 1991) included cross-validations. Whereas, Ebbeling et al. (1991) validated the protocol on subjects between 20 and 59 years of age, George et al. (1993 a) tested subjects between 18 and 29 years. Many of these treadmill protocols, including those developed by Ebbeling et al. (1991) and George et al. (1993 a), use treadmill speed and grade to predict $\dot{V}O_{2MAX}$. Unfortunately, treadmill speed calibration is rarely done. Therefore, an additional source of error is added. The administration of an overground walking or running test will help to circumvent this problem.

Overground Walking and Running Test Protocols

Overground walking and running tests developed using a fixed duration (time limit) or of distances less than one-mile are listed in Table 6. Overground walking and running tests developed using distances of one-mile are listed in Table 7. Overground walking and running tests developed using distances greater than one-mile are listed in Table 8. Correlations between predicted and measured $\dot{V}O_{2MAX}$ for the over-ground tests ranged from $r = 0.53$ to $r = 0.90$. No patterns in predictive accuracy could be identified when comparing tests of different distances. Some of the tests, such as the Cooper 12-minute run, are still commonly used today. Many of the protocols listed in Table 6, Table 7, and Table 8 were developed using only one gender (Cooper, 1968; Doolittle and Bigbee, 1967; Falls, 1965; Getchell et al., 1977; Jackson et al., 1990; Myles et al., 1980). Of the remaining tests, only those developed by Dolgener et al. (1994), Kline et al. (1987), and Oja et al. (1991) used subjects with a wide age range. The range of $\dot{V}O_{2MAX}$ values was not reported for most studies. Therefore, a comparison of subject aerobic capacities is not possible.

The Rockport Fitness Walking Test

Kline et al. (1987) originally validated the Rockport Fitness Walking Test (RFWT) on adults between the age 30 and 69 years. O'Hanley et al. (1987) found the one-mile walking test to accurately

predict $\dot{V}O_{2MAX}$ for males between 70 and 79, but significantly underestimate $\dot{V}O_{2MAX}$ for females between 70 and 79. Fenstermaker et al. (1992) also researched the use of the RFWT on an older population. The walking test was found to provide valid estimates for females ≥ 65 years of age. Coleman et al. (1987) evaluated the use of the RFWT on adults between 20 and 29 years. The equations were found to accurately estimate $\dot{V}O_{2MAX}$. However, Dolgener et al. (1994) found the RFWT to systematically overestimate $\dot{V}O_{2MAX}$ when used on college-aged individuals. In agreement with Dolgener et al. (1994), George et al. (1998) also found the RFWT to overestimate $\dot{V}O_{2MAX}$. Although these findings are in disagreement with those of Coleman et al. (1987), other differences between these studies exist. Dolgener et al. (1994) and George et al. (1998) also used post-exercise heart rate rather than HR_{AVG} . The use of post-exercise heart rate was not unfounded. Wilkie et al. (1987) found post-exercise heart rate to result in significant overestimates of $\dot{V}O_{2MAX}$. However, the differences between the two techniques were on average $1.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Thus, the researchers concluded that the use of post-exercise heart rate would result in acceptable $\dot{V}O_{2MAX}$ estimations (Wilkie et al., 1987). Widrick et al. (1992) also studied the use of the RFWT. In this study, the use of a treadmill instead of overground walking was found to allow for valid $\dot{V}O_{2MAX}$ estimates. No research was found in the literature pertaining to the validity of the RFWT using less than maximal walking speeds.

Table 2. Test protocols developed for estimating VO_{2MAX} using step testing.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	VO_{2MAX}	SEE	R	r^2	N	r
Astrand and Ryhming (1954)	VO_2 and heart rate	18	18-19	M	4.03+	0.28+	----	----	--	--
deVries et al. (1965)	Recovery heart rate (Harvard Step Test)	16	20-26	M	50.5 ± 9.87	6.35	----	0.587	--	--
	Recovery heart rate (Progressive Pulse Ratio Test)	16	20-26	M	50.5 ± 9.87	6.93	----	0.506	--	--
Francis and Brasher (1992)	Recovery heart rate	33	18-47	M	50.8 ± 9.1	5.43	----	0.659	10	0.98
Jette et al. (1976)	Age, weight, Recovery heart rate, and VO_2	59	15-74	M/F	36.0 ± 10.4	4.08	0.905	0.810*	--	--
McArdle et al. (1972)	Recovery heart rate (Queens College Test)	35	20.8 ± 1.1	F	37.5 ± 3.9	2.9	----	0.569	--	--
		6	21.2 ± 2.3	F	45.7 ± 4.0					
	Recovery heart rate (Skubic-Hodgkins Test)	35	20.8 ± 1.1	F	37.5 ± 3.9	3.5	----	0.412	--	--
		6	21.2 ± 2.3	F	45.7 ± 4.0					

Except where noted with a "+" values for VO_{2MAX} and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 3. Test protocols developed for estimating $\text{VO}_{2\text{MAX}}$ using cycle ergometry.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	$\text{VO}_{2\text{MAX}}$	SEE	R	r^2	N	r
Astrand and Ryhming (1954)	Heart rate @ 900 kpm	27	20-30	M	4.11+	0.43+	----	----	--	--
	Heart rate @ 1200 kpm	22	± 4.15			0.28+	----	----	--	--
	Heart rate @ 600 kpm	31	20-30	F	2.87+	0.42+	----	----	--	--
	Heart rate @ 900 kpm	29	± 2.91			0.27+	----	----	--	--
deVries et al. (1965)	Heart rate @ 900 kpm (Astrand-Ryhming Nomogram)	16	20-26	M	50.5 ± 9.87	0.359	----	0.542	--	--
	Heart rate (Sjostrand Test)	16	20-26	M	50.5 ± 9.87	4.74	----	0.769	--	--
Jessup (1975)	Heart rate	30	18-23	M	48.16 ± 5.46	----	----	0.423	30	0.65
McMurray et al. (1998)	Heart rate	15	7-13	M	48.1 ± 6.0	4.1	----	0.651	--	--
		18		F	42.5 ± 6.7					
Siconolfi et al. (1982)	Age and $\text{VO}_{2\text{MAX}}$ from Astrand-Ryhming Nomogram	63	20-69	M/F	$2.07 \pm 0.74+$	0.25+	----	0.884	--	--

Except where noted with a "+" values for $\text{VO}_{2\text{MAX}}$ and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 4. Test protocols developed for estimating $\text{VO}_{2\text{MAX}}$ using treadmill walking.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	$\text{VO}_{2\text{MAX}}$	SEE	R	r^2	N	r
Bonen et al. (1979)	VO_2 , VCO_2 , age, and heart rate	100	7-15	M	48.3 ± 5.1	4.1	0.62	0.384*	39	0.45
	VO_2 , heart rate, and height	100	7-15	M	$1.77 \pm 0.52+$	0.17+	0.95	0.903*	39	0.95
Coleman (1976)	Age, heart rate, and workload	15	22.67 ± 1.8	M	$4.49 \pm 0.79+$	0.45+	----	0.706	--	--
Ebbeling et al. (1991)	Speed, heart rate, age, speed*age, gender, and heart rate*age	117	20-59	M/F	42.4 ± 12.9	4.85	0.96	0.923*	22	0.96
Widrick et al. (1992)	1-mile walk time, heart rate, gender, age, and weight	145	37.8 ± 10.4	M/F	42.0 ± 12.3	≤ 5.26	----	0.828	--	--

Except where noted with a "+" values for $\text{VO}_{2\text{MAX}}$ and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 5. Test protocols developed for estimating VO_{2MAX} using treadmill jogging or running.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	VO_{2MAX}	SEE	R	r^2	N	r
George et al. (1993 a)	Speed, weight, gender, and heart rate	66	18-29	M/F	48.3 ± 6.2	3.2	0.84	0.706*	63	0.88
Hermiston and Faulkner (1971)	Age, heart rate, RER, TV, $FeCO_2$, and fat- free weight	36	34.0 ± 9.9	M	$3.26 \pm 0.52+$	----	0.90	0.810*	15	0.90
	Age, RER, TV, and fat-free weight	36	42.0 ± 9.9	M	$2.72 \pm 0.47+$	----	0.90	0.810*	13	0.90
Latin and Elias (1993)	Speed, percent grade, and heart rate	28	19-40	M	$4.26 \pm 0.5+$	0.48	----	0.723	--	--
		25		F	$2.68 \pm 0.4+$					
Metz and Alexander (1971)	RER and heart rate	30	12-13	M	50.88 ± 11.17	3.125	0.701	0.491*	30	0.396

Except where noted with a "+" values for VO_{2MAX} and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 6. Overground walking/running test protocols for estimating VO_{2MAX} using distances less than one-mile or a fixed period of time.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	VO_{2MAX}	SEE	R	r^2	N	r
Cooper (1968)	12-min walk/run distance	115	17-52	M	31-59	----	----	0.805	--	--
Doolittle & Bigbee (1967)	600 yard run time	9	14-15	M	----	----	----	0.810	--	--
Falls (1965)	50-yd dash, shuttle run, 600 yd run, and pull-ups	87	23-58	M	39.50 ± 7.60	4.72	0.724	0.524*	--	--
George et al. (1998)	¼ mile walk time, heart rate, gender, and weight	85	18-29	M/F	42.80 ± 6.60	3.67	----	0.689	--	--
MacNaughton et al. (1990)	5 min run distance	142	12-15	M/F	----	----	----	0.285-0.564	--	--
	15 min run distance	142	15-15	M/F	----	----	----	0.450-0.776	--	--

Except where noted with a "+" values for VO_{2MAX} and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 7. Overground walking/running test protocols for estimating VO_{2MAX} using a distance of one-mile.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	VO_{2MAX}	SEE	R	r^2	N	r
Cureton et al. (1995)	1 mile walk/run time, age, gender, and weight	490 263	8-25	M F	50.10 ± 4.70 45.0 ± 3.6	5.0 4.5	0.71 0.410	0.462	258	0.74
Dolgener (1994)	1-mile walk time, gender, heart rate, and weight	196	19.4 ± 2.74	M/F	$2.82 \pm 0.75+$	0.397+	0.84	0.706	78	0.86
Fenstermaker et al. (1992)	1-mile walk time, age, gender, heart rate, and weight	82	69.4 ± 4.2	F	21.05 ± 3.30	2.02	-----	0.624	--	--
George et al. (1993 b)	1-mile jog time, gender, weight, and heart rate	54	21.4 ± 2.7	M/F	46.6 ± 6.1	3.0	0.87	0.757*	52	0.84
Kline et al. (1987)	1-mile walk time, age, gender, heart rate, and weight	82 92	30-69	M F	42.2 ± 9.8 31.4 ± 8.4	5.0	-----	0.774	169	0.88

Except where noted with a "+" values for VO_{2MAX} and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

Table 8. Overground walking/running test protocols for estimating $\text{VO}_{2\text{MAX}}$ using distances greater than one-mile.

Reference	Variables	Estimation							Cross-Validation	
		N	Age	Gender	$\text{VO}_{2\text{MAX}}$	SEE	R	r^2	N	r
George et al. (1993 b)	1.5-mile time, gender, and weight	49	22.5 ± 3.0	M/F	48.1 ± 6.4	2.8	0.90	0.810*	47	0.82
Getchell et al. (1977)	1.5 mile run time	21	18-25	F	35.0-55.4	----	----	0.837	--	--
Jackson et al. (1990)	3-mile run time	50	21.7	M	54.23 ± 7.08	5.77	----	0.336	--	--
Larsen et al. (2002)	1.5 mile walk/run time, heart rate, gender, and body mass	101	20.5 ± 2.4	M/F	46.0 ± 6.0	2.87	0.90	0.810*	101	0.89
Myles et al. (1980)	2.4 km run time	32	23.2 ± 3.9	M	48.0 ± 5.1	----	----	0.774	--	--
	4.8 km run time							0.689	--	--
Oja et al. (1991)	2 km walk time, age heart rate, and BMI	34	20-65	M	48.0 ± 5.1	3.3	0.84	0.75	111	0.81
		28	20-65	F	48.0 ± 5.1	5.1	0.83	0.73	75	0.80

Except where noted with a "+" values for $\text{VO}_{2\text{MAX}}$ and SEE are in units of ml/kg/min. A "+" indicates units of liters/min. A "*" represents R^2 .

CHAPTER THREE

METHODOLOGY

Subjects

The subjects included 40 volunteers (20 males, 20 females) between the ages of 18 and 29 years. Subjects had either volunteered in response to fliers placed at various business locations throughout Bozeman, MT; or were recruited from various classes at Montana State University (MSU). Each subject completed a medical history questionnaire in order to screen for contraindications to performing maximal exercise. Informed consent documents were signed in accordance with the MSU Human Subjects Committee guidelines.

ProceduresMeasurement Schedule.

Each subject was required to visit both the Movement Science Lab located in Romney Gym and the indoor track in Shroyer Gym on the MSU campus for testing. A total of six visits were made within a four-week period with no less than 24 hours between visits. The subject's maximal oxygen uptake was measured in the Movement Science Lab on the first visit. No less than 48 hours later the subject performed the first of a series of one-mile Rockport Fitness Walking Tests (RFWTs) on the indoor track in Shroyer Gym. On this visit, the subject was instructed to walk at the fastest pace that could be maintained (WS_{MAX}). Heart rate data from the Maximal Oxygen Uptake ($\dot{V}O_{2MAX}$) test and the maximally paced RFWT was used to calculate the desired heart rate range for two lower intensity RFWTs. During the next two visits (visits #3 and #4), RFWTs using the lower heart rate ranges were performed (WS_{SUBMAX}). Assignment of walking tests for visits #3 and #4 were counter-balanced. Thus, one half of the subjects performed the RFWT with the higher heart rate range on the 3rd visit, whereas the other half performed this

test on the 4th visit. Finally, on the last day of testing, each subject repeated one of the three previously performed RFWTs allowing for the determination of test-retest reliability. The subject performed all tests at the same time of day (+/- 2 hours) to minimize any time of day effects on heart rate.

Maximal Oxygen Uptake Test.

On the first day of testing, the subject's height and weight were measured using a calibrated physician's beam scale (Healthometer, Bridgeview, IL). The subject was given a chance to warm-up on the treadmill prior to testing. During warm-up, subjects self-selected a walking or running treadmill speed to be used for the test. While the subject was warming up, the metabolic cart was calibrated using gases of known concentration. Following warm-up, the subject was fitted with a heart rate monitor and a mouthpiece connected to the gas collection tube on the metabolic cart. $\dot{V}O_{2MAX}$ was determined using the treadmill protocol originally described by Kline et al. (1987) for the original validation of the RFWT. Treadmill speed remained fixed during the test. Treadmill grade was 0% for the first stage and increased by 2.5% every two minutes thereafter. The test was terminated when the subject had reached volitional exhaustion despite verbal encouragement. The test was considered maximal if two of the four following criteria were satisfied (1) Respiratory exchange ratio ≥ 1.10 ; (2) Heart rate no more than 15 beats below the age predicted maximal heart rate ($220 - \text{age}$); (3) a rating of perceive exertion no less than 9 during the last stage; (4) or a leveling off of oxygen uptake (within $2.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) with an increase in treadmill grade. The highest oxygen uptake value, but within $2.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ of other nearby values, was accepted as the peak oxygen uptake. To prevent confusion this value ($\dot{V}O_{2PEAK}$) will hereafter be referred to as $\dot{V}O_{2MAX}$.

Administration of Walking Tests.

The RFWTs were performed on the indoor track located above the basketball courts in Shroyer Gym. The track requires $11\frac{1}{2}$ laps for one mile. Prior to testing, the subjects were fitted with a heart rate monitor and allowed to walk around the track for as long as needed in order to warm-up. The subjects were not required to perform a warm-up, but were recommended to walk around the track for at least five to ten minutes. Following warm-up, the subject was given instructions for the test. In order to determine walking

speed, a stopwatch was used to measure the time taken to walk past two marked posts 30 feet apart. These time measures, 12 total, and the total walk time were recorded to the hundredth of a second.

For the first RFWT (RFWT_{MAX}), the subject was instructed to walk at the fastest pace that could be maintained (WS_{MAX}). The subjects were given verbal encouragement to continue walking at a maximal pace.

The remaining RFWTs (RFWT_{15} and RFWT_{30}) were performed at submaximal walking intensities ($\text{WS}_{\text{SUBMAX}}$). Prior to these tests several calculations were made including the subject's standing heart rate reserve ($\text{HRR}_{\text{STAND}}$). Heart rate reserve is defined as the difference between the maximum heart rate (HR_{MAX}) and resting heart rate (Robergs and Roberts, 1997). To determine $\text{HRR}_{\text{STAND}}$, resting heart rate was taken for five minutes while the subject was standing quietly. This was done just prior to the first walking test. The lowest value recorded was used as the standing at rest value. The highest heart rate observed during the $\dot{\text{V}}\text{O}_{2\text{MAX}}$ test was used as the HR_{MAX} . The $\text{HRR}_{\text{STAND}}$ was then used to calculate a range of heart rates for two submaximal walking intensities. Percentages (15% and 30%) of $\text{HRR}_{\text{STAND}}$ were subtracted from the HR_{AVG} of the maximally paced RFWT to get the mean value for the two desired ranges. The 15% and 30% of $\text{HRR}_{\text{STAND}}$ were used in order to allow for a significant difference in the heart rate ranges. Practice walking tests were done in order to determine whether these percentages provided ranges that were not so close as to overlap.

Based upon pilot walking tests, a desired heart rate range of the mean $\pm$ five bpm was used. The watch of the heart rate monitor was set such that as the subject's heart rate approached the limits of the desired range it would provide an audible alarm. To allow for response time the watch was set to alarm if actual heart rate differed from the mean desired heart rate by three beats or more. When the alarm sounded, the subject could look at the watch and respond by either speeding up or slowing down.

Prediction of $\dot{\text{V}}\text{O}_{2\text{MAX}}$.

The generalized equations developed by Kline et al. (1987) and Dolgener et al. (1994) are presented as Equation 1 and Equation 2, respectively.

Equation 1 (Kline generalized equation)

$$\dot{V}O_{2MAX} = 132.853 - (0.0769 \cdot BW) - (0.3877 \cdot A) + (6.3150 \cdot G) - (3.2649 \cdot T) - (0.1565 \cdot HR)$$

Equation 2 (Dolgener generalized equation)

$$\dot{V}O_{2MAX} = 94.6440 - (0.0819 \cdot BM) - (0.3232 \cdot A) + (8.4073 \cdot G) - (1.6157 \cdot T) - (0.1146 \cdot HR)$$

where BW is body weight (pounds), BM is body mass (kilograms), A is age (years), G is gender (Female=0, Male=1), T is time to complete the walk expressed in minutes and hundredths of a minute, and HR is heart rate.

Instrumentation

Maximal Oxygen Uptake Measurement

During maximal testing, expired gases were measured and analyzed using a SensorMedics 2900 metabolic cart (SensorMedics, Yorba Linda, CA). The duration of the sample interval was 20 seconds. The gas analyzers and expired volume meter were calibrated in accordance with the manufacturer's recommendations prior to testing each subject. Certified gases of known concentration were used to calibrate the oxygen and carbon dioxide analyzers. A calibrated three-liter syringe (Model D, SensorMedics Corporation, Yorba Linda, CA) was used to calibrate the pneumotach for ventilation measurement. Heart rate was monitored using a Polar Vantage NV telemetric heart rate monitoring/recording system (Polar, Stamford, CT) set for a five-second sample interval.

Rockport Fitness Walking Tests

Heart rate was monitored using the Polar Vantage NV telemetric heart rate monitoring/recording system (Polar, Stamford, CT). The monitor was set to average heart rate taken during five-second intervals. Stopwatches were used for walking time and speed measurements. Time values were recorded to the hundredth of a second.

Statistical Analysis

In order to determine whether the Kline or the Dolgener generalized equations provided better estimates of $\dot{V}O_{2MAX}$, the heart rate data was entered into the respective equations. The Kline and Dolgener equations are given below. Both equations use age, time to complete the walk and gender as independent variables. However, the Dolgener study used post-exercise heart rate, while the Kline study used the average heart rate over the last two minutes of the walk to estimate $\dot{V}O_{2MAX}$. Therefore, the post-exercise heart rate was used with the Dolgener equation, while HR_{AVG} was used with the Kline equation.

The mean values of the $\dot{V}O_{2MAX}$ estimations from both Equation 1 and Equation 2 were compared with the mean measured $\dot{V}O_{2MAX}$ value using two-factor repeated measures analysis of variance (ANOVA). Pearson product moment correlations and standard estimate of error values were calculated to compare the estimated (six total) and actual $\dot{V}O_{2MAX}$ values.

Intraclass correlation coefficients and standard error of measurement values were used to assess test-retest reliability. Furthermore, a two-factor repeated measures ANOVA was used to compare walk times between the mark points and identify significant changes between laps. An alpha level of 0.05 was used to establish statistical significance for all tests.

CHAPTER FOUR

RESULTS

Subjects

Forty-four subjects (22 males, 22 females) participated in the study. Time constraints prevented four subjects (2 males, 2 females) from completing testing. Therefore, results are based on 40 subjects (20 males, 20 females). The subjects' $\dot{V}O_{2MAX}$ values ranged from 33 to 75 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The mean $\dot{V}O_{2MAX}$ values indicated that the subjects in this study tended to have higher fitness levels than the subjects evaluated by Kline et al. (1987), Dolgener et al. (1994), George et al. (1998), and Coleman et al. (1987). In comparison to the subjects of the Kline study, the subjects tended to be younger, have a higher maximum heart rate, but a comparable bodyweight. In contrast, the subjects tended to be older, have a lower maximum heart rate and be heavier than the subjects of the Dolgener study. Descriptive characteristics of the subjects are given in Table 9.

Table 9. Descriptive characteristics of the subjects. Values are expressed as mean value $\pm$ standard deviation; parentheses denote the range of values observed.

	Males (n=20)	Females (n=20)	Total (n=40)
Age (years)	24 $\pm$ 2.8 (19-29)	22.2 $\pm$ 1.9 (18-27)	23.1 $\pm$ 2.5 (18-29)
Body Mass (kilograms)	82.58 $\pm$ 12.80 (64.24-111.41)	64.15 $\pm$ 8.35 (52.10-81.81)	73.37 $\pm$ 14.16 (52.10-111.41)
Body Height (centimeters)	177.04 $\pm$ 9.91 (155.58-195.58)	163.58 $\pm$ 8.89 (133.67-177.80)	170.18 $\pm$ 11.68 (133.67-195.58)
Maximum Heart Rate (beats/minute)	193 $\pm$ 8 (178-205)	199 $\pm$ 9 (181-216)	196 $\pm$ 9 (178-216)
$\dot{V}O_{2MAX}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	57.58 $\pm$ 7.87 (41.10-73.27)	49.00 $\pm$ 6.89 (32.74-59.71)	53.29 $\pm$ 8.50 (32.74-73.27)

$\dot{V}O_{2MAX}$ Comparisons

Comparisons of measured to predicted $\dot{V}O_{2MAX}$ values for males and females are presented in Tables 10 and 11, respectively. Table 12 presents a comparison of measured to predicted $\dot{V}O_{2MAX}$ values for all subjects. Correlation coefficients (r), SEEs, total errors (E), bias, and P-values are also given in Tables 10, 11, and 12.

Table 10 indicates that males were systematically underestimated by the Kline and Dolgener generalized equations under all walking conditions. $\dot{V}O_{2MAX}$ prediction values from the Kline equation tended to decrease with a corresponding decrease in walking speed. In contrast, $\dot{V}O_{2MAX}$ prediction values from the Dolgener equation tended to be greatest at the middle walking speed (RFTW₁₅). Predicted to measured $\dot{V}O_{2MAX}$ correlation values ranged from $r = 0.58$ to $r = 0.73$ for the Kline equation. The Dolgener equation had a similar range of correlations ($r = 0.63$ to 0.80). The SEE and Bias values from the Kline equation were on average slightly less than those from the Dolgener equation. SEE values ranged from (3.18 to $5.33 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and (3.67 to $5.00 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for the Kline and Dolgener equations, respectively. Bias values ranged from (-2.92 to $-4.92 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and (-4.52 to $-4.90 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for the Kline and Dolgener equations, respectively. All P-values were less than 0.01.

Table 11 indicates that females were systematically underestimated by the Kline and Dolgener generalized equations under all walking conditions. $\dot{V}O_{2MAX}$ prediction values from the Kline equation tended to decrease with a corresponding decrease in walking speed. In contrast, $\dot{V}O_{2MAX}$ prediction values from the Dolgener equation tended to be greatest at the middle walking speed (RFTW₁₅). Predicted to measured $\dot{V}O_{2MAX}$ correlation values ranged from $r = 0.70$ to 0.88 for the Kline equation. The Dolgener equation had a similar range of correlations ($r = 0.72$ to 0.86). The SEE and Bias values from the Kline equation were on average slightly less than those from the Dolgener equation. SEE values ranged from (4.86 to $8.88 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and (7.87 to $8.76 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for the Kline and Dolgener equations, respectively. Bias values ranged from (-1.81 to $-5.00 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and (-4.48 to $-5.51 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) for the Kline and Dolgener equations, respectively. All P-values were less than 0.01.

Many of the patterns seen in Tables 10 and 11 were also present in Table 12. For the group

including all subjects, the Kline and Dolgener generalized equations systematically underestimated $\dot{V}O_{2MAX}$ under all walking conditions. $\dot{V}O_{2MAX}$ prediction values from the Kline equation tended to decrease with a corresponding decrease in walking speed. In contrast, $\dot{V}O_{2MAX}$ prediction values from the Dolgener equation tended to be greatest at the middle walking speed (RFTW₁₅). Predicted to measured $\dot{V}O_{2MAX}$ correlation values ranged from $r = 0.75$ to 0.89 for the Kline equation. The range of correlations for the Dolgener equation was ($r = 0.73$ to 0.79). The SEE and Bias values from the Kline equation were on average slightly less than those from the Dolgener equation. SEE values ranged from (6.84 to 9.04 $ml \cdot kg^{-1} \cdot min^{-1}$) and (8.23 to 9.15 $ml \cdot kg^{-1} \cdot min^{-1}$) for the Kline and Dolgener equations, respectively. Bias values ranged from (-2.61 to -4.63 $ml \cdot kg^{-1} \cdot min^{-1}$) and (-4.19 to -4.56 $ml \cdot kg^{-1} \cdot min^{-1}$) for the Kline and Dolgener equations, respectively. All P-values were less than 0.01 .

Figure 1 illustrates the relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Kline equation for the RFTW_{MAX}. In Figure 1, the Kline equation appears to have uniformly underestimated $\dot{V}O_{2MAX}$.

The relationship between the measured $\dot{V}O_{2MAX}$ value and predicted $\dot{V}O_{2MAX}$ from the Kline equation for the RFTW₁₅ is depicted in Figure 2. In Figure 2, the Kline equation tends to underestimate $\dot{V}O_{2MAX}$. Furthermore, there appears to be a tendency for the underestimation to become greater for subjects with higher fitness levels.

Figure 3 illustrates the relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Kline equation for the RFTW₃₀. Under this condition, the Kline equation's underestimation tended to decrease with an increase in the subjects' fitness levels. Figure 5 also appears to show one subject whose predicted $\dot{V}O_{2MAX}$ value is much less than those of the other subjects. Although this data point appears to have a great deal of leverage, its removal did not result in a change of significance ($P < 0.01$).

Figure 4 illustrates the relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Dolgener equation for the RFTW_{MAX}. The relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Dolgener equation for the RFTW₁₅ is depicted in Figure 5. Figure 6 illustrates the relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Dolgener equation for the RFTW₃₀. In Figures 4, 5, and 6 the Dolgener equation tends to underestimate $\dot{V}O_{2MAX}$. Furthermore,

Table 10. Comparison of measured and estimated $\text{VO}_{2\text{MAX}}$ values for males. $\text{VO}_{2\text{MAX}}$ values are reported as mean with standard error values within parentheses.

Sample	Measurement Method (ml/kg/min)	$\text{VO}_{2\text{MAX}}$ (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
Men	Actual $\text{VO}_{2\text{MAX}}$	58.51 (1.84)					
(n=20)	Kline	53.88 (1.55)	0.58	± 8.25	± 5.33	- 2.92	0.007992 ^s
	Kline 15	53.21 (1.06)	0.85	± 7.11	± 3.18	- 3.93	0.000104 ^s
	Kline 30	51.15 (1.29)	0.73	± 9.19	± 4.27	- 4.92	0.000012 ^s
	Dolgener	51.70 (0.61)	0.63	± 9.52	± 5.00	- 4.52	0.000265 ^s
	Dolgener 15	52.57 (0.59)	0.80	± 8.57	± 3.67	- 4.90	0.000486 ^s
	Dolgener 30	52.20 (0.65)	0.76	± 8.82	± 4.03	- 4.79	0.000263 ^s

Kline = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Kline et al.; Dolgener = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Dolgener et al. ; 15 = walking test that was performed at 15% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; 30 = walking test that was performed at 30% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; r = Pearson Product Moment (correlation coefficient); E = total error; SEE = standard estimate of error; P-value from a two-factor, repeated measures analysis of variance; ^s = statistically significant difference($\alpha=0.05$).

Table 11. Comparison of measured and estimated $\text{VO}_{2\text{MAX}}$ values for females. $\text{VO}_{2\text{MAX}}$ values are reported as mean with standard error values within parentheses.

Sample	Measurement Method (ml/kg/min)	$\text{VO}_{2\text{MAX}}$ (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
Women	Actual $\text{VO}_{2\text{MAX}}$	49.57 (1.58)					
(n=20)	Kline	46.32 (0.94)	0.88	± 5.04	± 2.46	- 2.58	0.001613 ^s
	Kline 15	46.28 (1.17)	0.86	± 4.86	± 2.65	- 1.81	0.000740 ^s
	Kline 30	43.56 (2.10)	0.70	± 8.88	± 3.88	- 5.00	0.000768 ^s
	Dolgener	42.71 (0.47)	0.79	± 8.76	± 3.25	- 5.51	0.000026 ^s
	Dolgener 15	43.58 (0.52)	0.86	± 7.87	± 2.65	- 5.22	0.000063 ^s
	Dolgener 30	42.92 (1.01)	0.72	± 8.23	± 3.75	- 4.48	0.000009 ^s

Kline = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Kline et al.; Dolgener = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Dolgener et al. ; 15 = walking test that was performed at 15% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; 30 = walking test that was performed at 30% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; r = Pearson Product Moment (correlation coefficient); E = total error; SEE = standard estimate of error; P-value from a two-factor, repeated measures analysis of variance; ^s = statistically significant difference ($\alpha=0.05$).

Table 12. Comparison of measured and estimated $\text{VO}_{2\text{MAX}}$ values for all subjects. $\text{VO}_{2\text{MAX}}$ values are reported as mean with standard error values within parentheses.

Sample	Measurement Method (ml/kg/min)	$\text{VO}_{2\text{MAX}}$ (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
All Subjects	Actual $\text{VO}_{2\text{MAX}}$	54.04 (1.40)					
(n=40)	Kline	50.10 (1.08)	0.77	± 6.84	± 4.23	- 2.61	0.000079 ^s
	Kline 15	49.74 (0.96)	0.89	± 6.09	± 2.93	- 3.16	0.000000 ^s
	Kline 30	47.36 (1.36)	0.75	± 9.04	± 4.41	- 4.63	0.000000 ^s
	Dolgener	47.20 (0.81)	0.73	± 9.15	± 4.59	- 4.56	0.000000 ^s
	Dolgener 15	48.08 (0.82)	0.79	± 8.23	± 4.04	- 4.19	0.000000 ^s
	Dolgener 30	47.56 (0.95)	0.78	± 8.53	± 4.14	- 4.39	0.000000 ^s

Kline = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Kline et al.; Dolgener = generalized equation for predicting $\text{VO}_{2\text{MAX}}$ developed by Dolgener et al. ; 15 = walking test that was performed at 15% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; 30 = walking test that was performed at 30% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; r = Pearson Product Moment (correlation coefficient); E = total error; SEE = standard estimate of error; P-value from a two-factor, repeated measures analysis of variance; ^s = statistically significant difference($\alpha=0.05$).

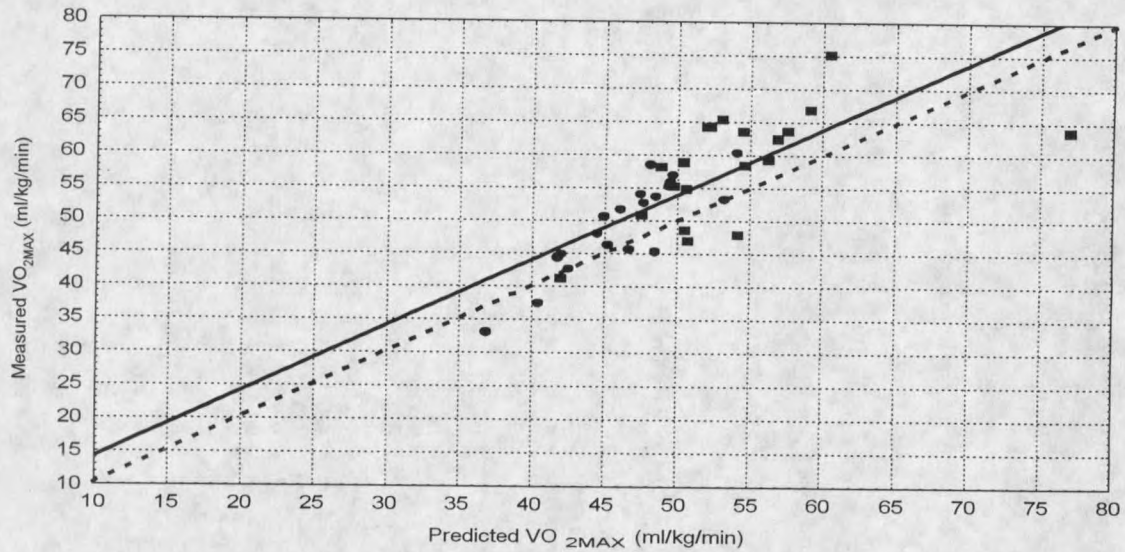


Figure 1. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the walking test performed at the subjects' fastest walking speed (RFTW_{MAX}). Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

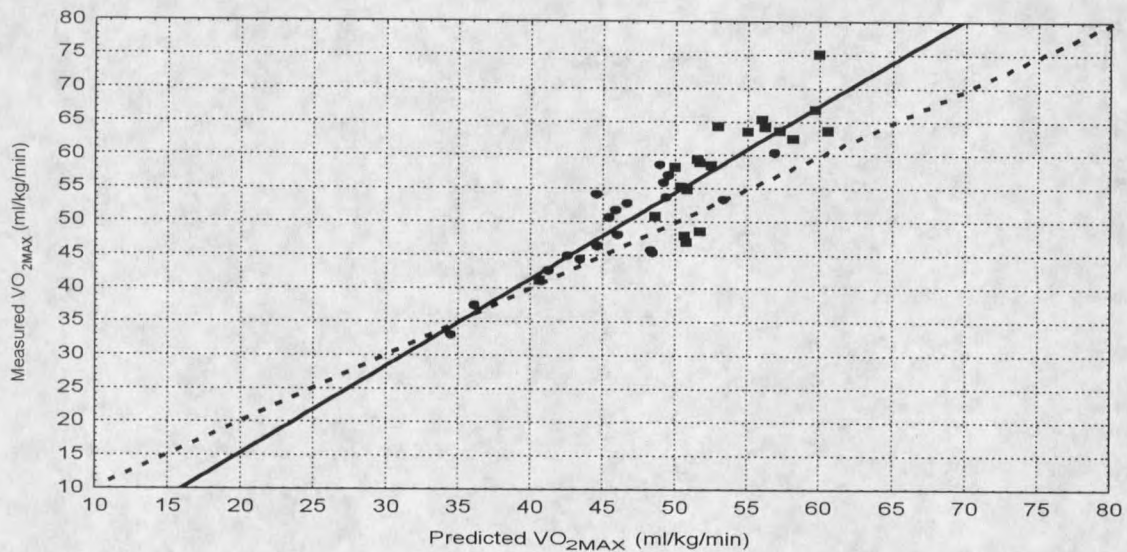


Figure 2. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the intermediate intensity, walking test. Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

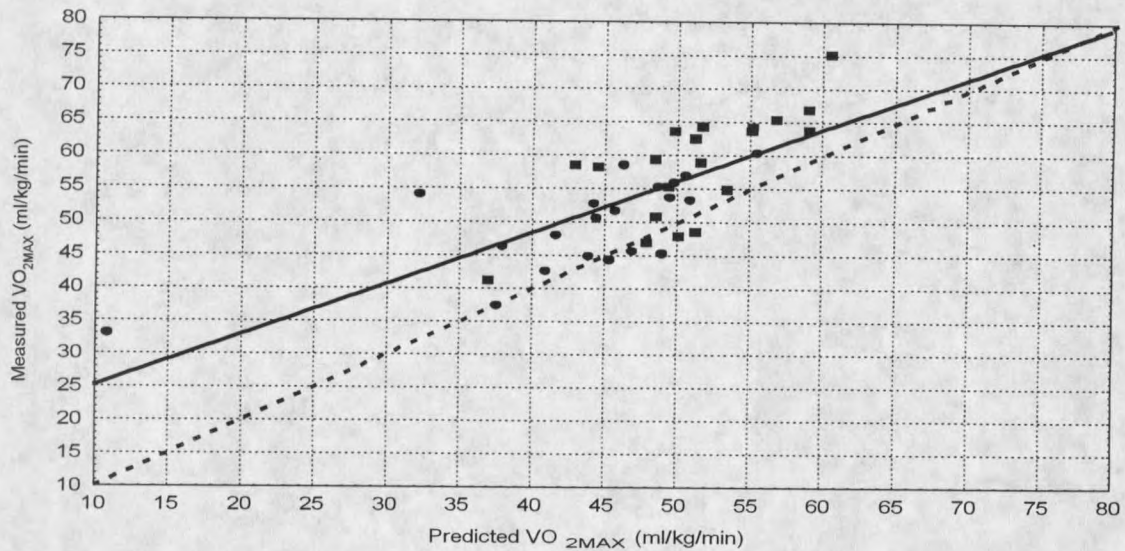


Figure 3. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the lowest intensity, walking test. Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

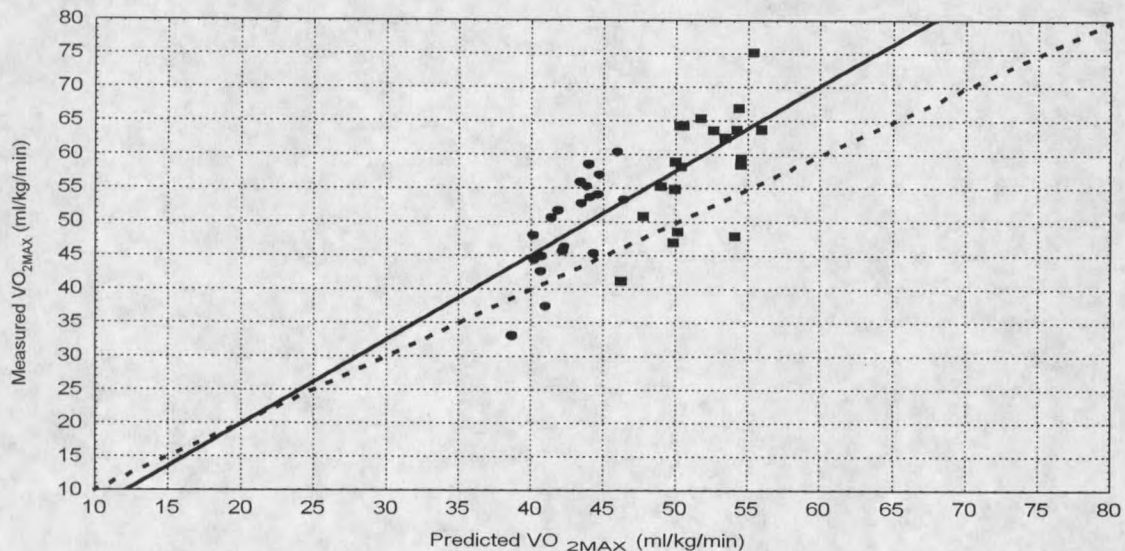


Figure 4. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994). The data is from the walking test performed at the subjects' fastest walking speed (RFWT_{MAX}). Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

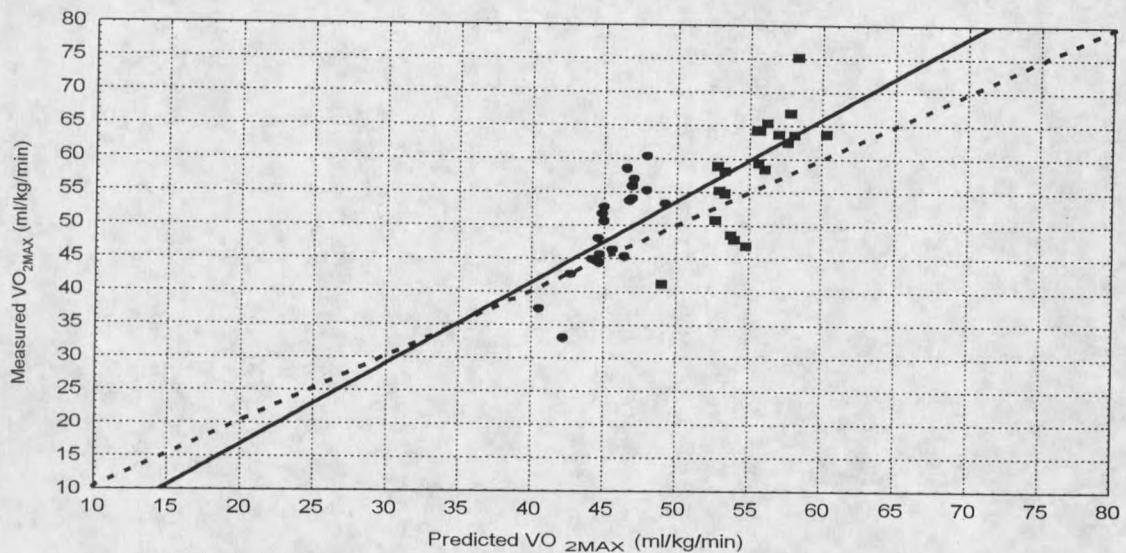


Figure 5. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994). The data is from the intermediate intensity, walking test. Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

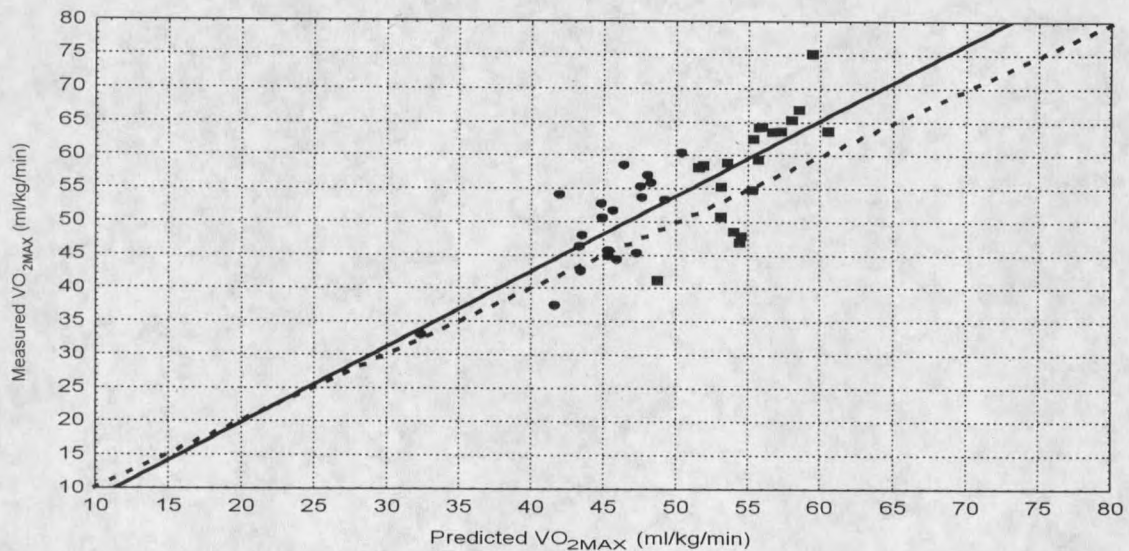


Figure 6. Scatterplot depicts the relationship between measured $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994). The data is from the lowest intensity, walking test. Circles represent females (n=20); squares represent males (n=20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

there appears to be a tendency for the underestimation to become greater for subjects with higher fitness levels.

In order to determine whether the Kline or the Dolgener equations provide acceptable estimates of $\dot{V}O_{2MAX}$, a comparison between actual and predicted $\dot{V}O_{2MAX}$ values was made. In addition to the comparisons shown in Table 10, Table 11, Table 12, and Figures 1 through 6, the criterion used by Dolgener et al. (1994) and George et al. (1998) was used to determine acceptable estimates. Dolgener et al. (1994) and George et al. (1998) used a difference no more than $4.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ to identify acceptable estimates. Table 13 shows the percentage of acceptable estimates provided by the two prediction equations.

Table 13. Percentage of the estimates of $\dot{V}O_{2MAX}$ from the prediction equations within $4.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ of the measured values.

Equation	Maximal Intensity	Test	
		Moderate Intensity	Low Intensity
Kline et al. (1987)	42.5%	50%	35%
Dolgener et al. (1994)	27.5%	30%	27.5%

Test-Retest Reliability

Test-retest data from the maximally paced walking test (RFWT_{MAX}) are provided in Table 14. There were no statistically significant differences between mean values for $\dot{V}O_{2MAX}$, body mass, heart rate, or time for the two trials ($P > 0.05$). For heart rate, walk time, body mass and $\dot{V}O_{2MAX}$ prediction the two trial intraclass correlations ($R_{XX(K=2)}$) were no less than 0.93. For heart rate, walk time, body mass and $\dot{V}O_{2MAX}$ prediction the one trial intraclass correlations ($R_{XX(K=1)}$) were no less than 0.87. The standard error of the measurement (SEM) for body mass was ± 0.88 kilograms. The SEM values for time, $\text{HR}_{AVERAGE}$, $\text{HR}_{POST-EXERCISE}$, Kline estimation of $\dot{V}O_{2MAX}$, and Dolgener estimation of $\dot{V}O_{2MAX}$ were ± 0.35 minutes, ± 6.25 bpm, ± 6.96 bpm, $\pm 1.18 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, and $\pm 0.78 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively.

Table 14. Test-retest reliability data from the maximally paced walking test (RFTW_{MAX}). Values are expressed as mean value $\pm$ standard error (n=14).

	Trial 1	Trial 2	*P-value	[†] R _{XX} (k=2)	[†] R _{XX} (k=1)	*SEM
Body Mass (kilograms)	73.59 $\pm$ 4.49	73.41 $\pm$ 4.55	0.299	> 0.99	> 0.99	$\pm$ 0.88
Time (minutes)	12.42 $\pm$ 0.36	12.29 $\pm$ 0.48	0.356	0.97	0.95	$\pm$ 0.35
HR _{AVERAGE} (beats/minute)	158 $\pm$ 5.0	160 $\pm$ 4.8	0.447	0.94	0.88	$\pm$ 6.25
HR _{POST-EXERCISE} (beats/minute)	158 $\pm$ 5.4	159 $\pm$ 5.2	0.603	0.93	0.87	$\pm$ 6.96
K* $\dot{V}O_{2MAX}$ - (ml/kg/min)	49.60 $\pm$ 1.57	49.75 $\pm$ 1.75	0.738	0.98	0.96	$\pm$ 1.18
D* $\dot{V}O_{2MAX}$ - (ml/kg/min)	47.40 $\pm$ 1.40	47.46 $\pm$ 1.39	0.846	0.99	0.97	$\pm$ 0.78

* P-value is from a two-factor, repeated measures analysis of variance.

[†] R_{XX} (k=2) is intraclass reliability for two trials.

[†] R_{XX} (k=1) is intraclass reliability for one trial.

* SEM is the standard error of the measurement.

K* values were calculated using the generalized equation developed by Kline et al.

D* values were calculated using the generalized equation developed by Dolgener et al.

Test-retest data from the submaximal walking tests (RFTW₁₅ and RFTW₃₀) are provided in Tables 15 and 16, respectively. For the higher-intensity, submaximal-walking test (RFTW₁₅), there were no statistically significant differences between mean values for predicted $\dot{V}O_{2MAX}$, body mass, heart rate, or time for the two tests (Table 15). However, for the lower-intensity submaximal-walking test (RFTW₃₀), there were statistically significant differences between mean values for predicted $\dot{V}O_{2MAX}$, body mass, and time for the two tests (Table 16). Subject body mass tended to decrease from Trial 1 to Trial 2 (P = 0.030). The mean one-mile walk time decreased from 14.82 to 14.20 minutes (P = 0.015). Estimated $\dot{V}O_{2MAX}$, on average, increased from (47.14 to 49.36 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) and (47.55 to 48.65 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹) for the Kline and Dolgener equations, respectively.

For RFWT₁₅ and RFWT₃₀, intraclass correlations for k=2 and k=1 were no less than 0.95. For RFWT₁₅ the SEM values for body mass, time, HR_{AVERAGE}, HR_{POST-EXERCISE}, Kline estimation of $\dot{V}O_{2MAX}$, and Dolgener estimation of $\dot{V}O_{2MAX}$ were ± 1.66 kilogramss, ± 0.23 minutes, ± 1.75 bpm, ± 4.11 bpm, ± 0.89 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹, and ± 0.69 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹, respectively. For RFWT₃₀ the SEM values for body mass, time, HR_{AVERAGE}, HR_{POST-EXERCISE}, Kline estimation of $\dot{V}O_{2MAX}$, and Dolgener estimation of $\dot{V}O_{2MAX}$ were ± 1.49 kilogramss, ± 0.55 minutes, ± 1.48 bpm, ± 2.92 bpm, ± 1.82 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹, and ± 0.95 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹, respectively.

Table 15. Test-retest reliability data from the higher intensity submaximal-walking test (RFWT₁₅). Values are expressed as mean value $\pm$ standard error (n=13).

	Trial 1	Trial 2	*P-value	[†] R _{XX} (k=2)	[‡] R _{XX} (k=1)	*SEM
Body Mass (kilograms)	73.59 $\pm$ 3.88	72.78 $\pm$ 3.74	0.191	> 0.99	> 0.99	± 1.66
Time (minutes)	12.42 $\pm$ 0.22	12.34 $\pm$ 0.20	0.412	0.95	0.91	± 0.23
HR _{AVERAGE} (beats/minute)	150 $\pm$ 5.2	150 $\pm$ 5.4	0.961	> 0.99	0.99	± 1.75
HR _{POST-EXERCISE} (beats/minute)	149 $\pm$ 5.1	149 $\pm$ 5.8	1.000	0.98	0.95	± 4.11
K* $\dot{V}O_{2MAX}$ - (ml/kg/min)	50.66 $\pm$ 1.27	50.85 $\pm$ 1.37	0.603	0.98	0.96	± 0.89
D* $\dot{V}O_{2MAX}$ - (ml/kg/min)	48.33 $\pm$ 1.34	48.43 $\pm$ 1.47	0.743	0.99	0.98	± 0.69

* P-value is from a two-factor, repeated measures analysis of variance.

[†] R_{XX} (k=2) is intraclass reliability for two trials.

[‡] R_{XX} (k=1) is intraclass reliability for one trial.

* SEM is the standard error of the measurement.

K* values were calculated using the generalized equation developed by Kline et al.

D* values were calculated using the generalized equation developed by Dolgener et al.

Table 16. Test-retest reliability data from the lower intensity submaximal-walking test (RFTW₃₀). Values are expressed as mean value $\pm$ standard error (n=13).

	Trial 1	Trial 2	*P-value	[†] R _{XX} (k=2)	[†] R _{XX} (k=1)	[☆] SEM
Body Mass (kilograms)	74.37 $\pm$ 3.53	73.73 $\pm$ 3.41	0.030 ^s	> 0.99	> 0.99	$\pm$ 1.49
Time (minutes)	14.82 $\pm$ 0.55	14.20 $\pm$ 0.47	0.015 ^s	0.95	0.91	$\pm$ 0.55
HR _{AVERAGE} (beats/minute)	120 $\pm$ 4.5	120 $\pm$ 4.5	0.374	> 0.99	0.99	$\pm$ 1.48
HR _{POST-EXERCISE} (beats/minute)	119 $\pm$ 4.4	118 $\pm$ 3.9	0.748	0.98	0.96	$\pm$ 2.92
K* $\dot{V}O_{2MAX}$ - (ml/kg/min)	47.14 $\pm$ 2.31	49.36 $\pm$ 2.14	0.010 ^s	0.97	0.95	$\pm$ 1.82
D* $\dot{V}O_{2MAX}$ - (ml/kg/min)	47.55 $\pm$ 1.78	48.65 $\pm$ 1.70	0.013 ^s	0.99	0.98	$\pm$ 0.95

* P-value is from a two-factor, repeated measures analysis of variance.

[†] R_{XX} (k=2) is intraclass reliability for two trials.

[†] R_{XX} (k=1) is intraclass reliability for one trial.

[☆] SEM is the standard error of the measurement.

K* values were calculated using the generalized equation developed by Kline et al.

D* values were calculated using the generalized equation developed by Dolgener et al.

^s denotes statistical significance with an alpha level of 0.05.

Subject Speed Comparisons

Analysis of the individual lap walking speeds for RFTW_{MAX} identified the first lap as significantly faster than all other laps ($P < 0.05$) except laps 2, 3, and 12. Analysis of lap walking speeds for RFTW₁₅ revealed no significant differences. Analysis of the individual lap walking speeds for RFTW₃₀ identified the first lap as significantly faster than laps 8, 9, 10, 11, and 12 ($P < 0.05$). Figure 7 illustrates the individual mean lap speeds during the RFTW_{MAX}, RFTW₁₅, and RFTW₃₀. Under all walking conditions, walking speed for the first lap tended to be faster than walking speed for all other laps.

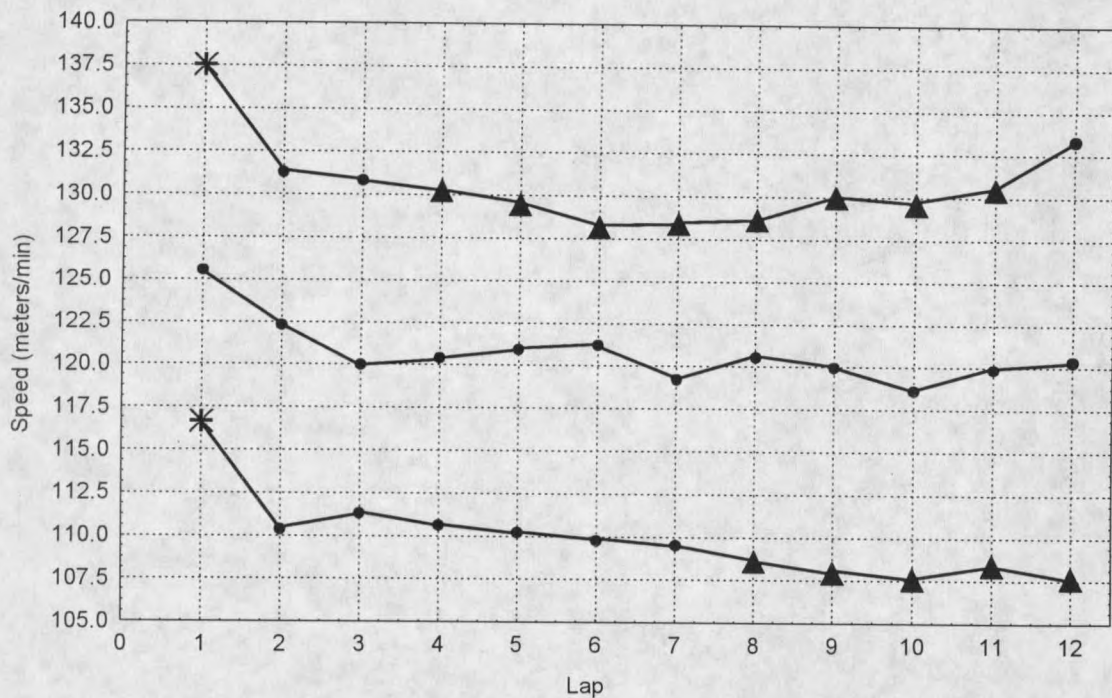


Figure 7. Walking speeds vs. lap. Top row is from the walking test performed at the maximal walking pace. Middle row is from the walking test performed at the intermediate intensity. Bottom row is from the walking test performed at the low intensity. Stars represent laps with significantly faster speeds than laps denoted with triangles ($P < 0.05$). Circles indicated laps not significantly different than other laps. Averages are based on the first trial performed by each subject ($n=40$).

Heart Rate and Walk Time Comparisons

ANOVA comparison of heart rate data from the RFT_{MAX} and RFT_{15} revealed no significant differences between post-exercise heart rate and average heart rate during the last two minutes of walking, ($P > 0.05$). However, ANOVA comparison of heart rate data from the RFT_{30} did result in a significant difference between post-exercise heart rate and average heart rate, ($P = 0.008$). Mean heart rate values from both techniques under all three walking conditions (RFT_{MAX} , RFT_{15} , and RFT_{30}) are presented in Table 17. HR_{AVG} for the RFT_{MAX} tended to be lower than post-exercise heart rate. In contrast, for RFT_{15} and RFT_{30} , HR_{AVG} tended to be slightly higher than post-exercise heart rate. The standard error of the mean tended to be smaller for the submaximal walking speeds (RFT_{15} and RFT_{30}). However, the heart rate monitor was used to control walking intensity for RFT_{15} and RFT_{30} .

Table 17. Heart rate values for the maximal, moderate, and low intensity walk tests. Values are expressed as mean value $\pm$ standard error (n=40).

	Measure	Males (n=20)	Females (n=20)	All Subjects (n=40)
RFTW _{MAX}	Average heart rate	154.0 $\pm$ 4.1	167.3 $\pm$ 3.6	160.7 $\pm$ 2.9
	Post-exercise heart rate	154.1 $\pm$ 4.2	168.3 $\pm$ 3.7	161.2 $\pm$ 3.0
	P-value	0.992	0.287	0.381
RFTW ₁₅	Average heart rate	135.4 $\pm$ 4.2	148.4 $\pm$ 3.4	141.9 $\pm$ 2.9
	Post-exercise heart rate	134.7 $\pm$ 4.2	147.6 $\pm$ 3.7	141.1 $\pm$ 2.9
	P-value	0.149	0.567	0.297
RFTW ₃₀	Average heart rate	118.5 $\pm$ 4.5	131.6 $\pm$ 3.4	125.1 $\pm$ 3.0
	Post-exercise heart rate	117.6 $\pm$ 4.5	130.4 $\pm$ 3.4	124.0 $\pm$ 2.9
	P-value	0.158	0.018 ^s	0.008 ^s

RFTW_{MAX} refers to the one-mile walking test performed at the fastest pace the subjects could maintain. RFTW₁₅ is the one-mile walking test performed at an intermediate intensity. RFTW₃₀ is the one-mile walking test performed at a low intensity. P-value is from a two-factor, repeated measures analysis of variance. ^s denotes statistical significance with an alpha level of 0.05.

A comparison of HR_{AVG} values to the ranges prescribed for the submaximal intensity, walking tests was performed. Of the 106 submaximal walk test trials, the HR_{AVG} was found to be outside of the prescribed range during 12 of these trials. On average, the subjects' heart rate was found to be in the middle ($\pm$ 1 bpm) of the prescribed range. The values that did not fall within the prescribed range were as many as 4 bpm above or 8 bpm below the desired range.

Table 18 lists the mean walk times for the maximal, moderate, and low intensity walk tests. A comparison of mean walk times between the moderate (RFTW₁₅) and maximal (RFTW_{MAX}) walk intensities revealed a significant difference for all groups ($P < 0.05$). A comparison of mean walk times

between the moderate (RFTW₁₅) and maximal (RFTW₃₀) walk intensities also revealed a significant difference for all groups ($P < 0.05$).

Table 18. Mean walk times for the maximal, moderate, and low intensity walk tests. Values are expressed as mean value $\pm$ standard error (n=40).

	Males (n=20)	Females (n=20)	All Subjects (n=40)
RFTW _{MAX}	11.85 $\pm$ 0.22	12.53 $\pm$ 0.25	12.19 $\pm$ 0.17
RFTW ₁₅	12.71 $\pm$ 0.31	13.44 $\pm$ 0.33	13.07 $\pm$ 0.23
RFTW ₃₀	14.14 $\pm$ 0.43	15.07 $\pm$ 0.63	14.60 $\pm$ 0.39

RFTW_{MAX} refers to the one-mile walking test performed at the fastest pace the subjects could maintain. RFTW₁₅ is the one-mile walking test performed at an intermediate intensity. RFTW₃₀ is the one-mile walking test performed at a low intensity. P-value is from a two-factor, repeated measures analysis of variance. ^s denotes statistical significance with an alpha level of 0.05.

Figure 8 depicts the relationship between walk time and heart rate for the RFTW_{MAX} and RFTW₁₅. Figure 9 depicts the relationship between walk time and heart rate for the RFTW₁₅ and RFTW₃₀. The slope of the lines in Figure 8 tends to be steeper than those in Figure 9. This indicates that the relationship between heart rate and walk time changes with changes in walk intensity.

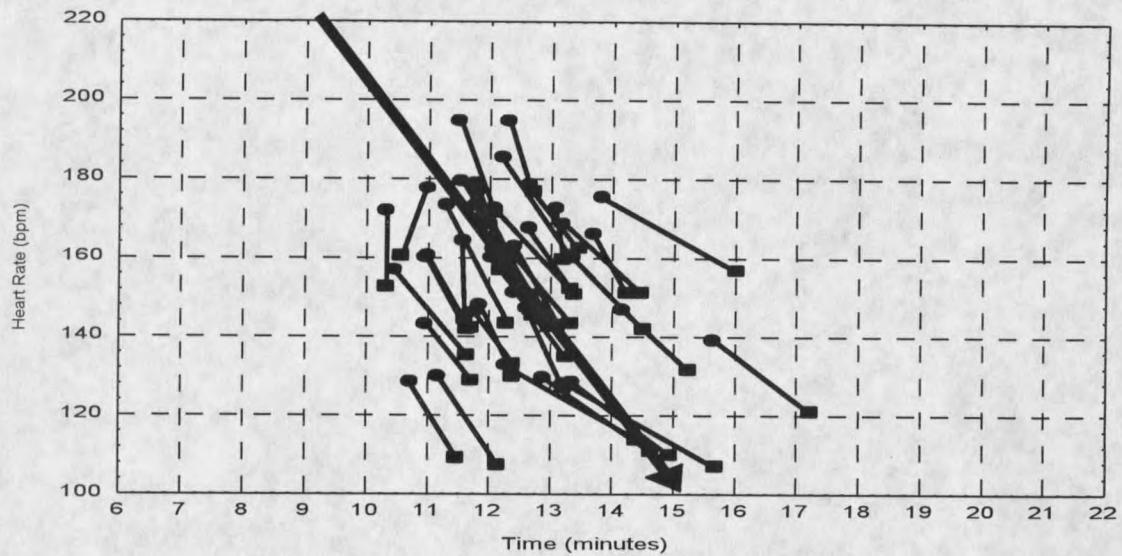


Figure 8. Heart rate versus walk time for the maximal and moderate intensity walk tests. Circles represent data from the maximal intensity walk test (RFTW_{MAX}). Squares represent data from the moderate intensity walk test (RFTW₁₅). The arrow represents the average change in the (heart rate/time) ratio seen with a change in walk intensity from maximal to moderate intensity (n=40).

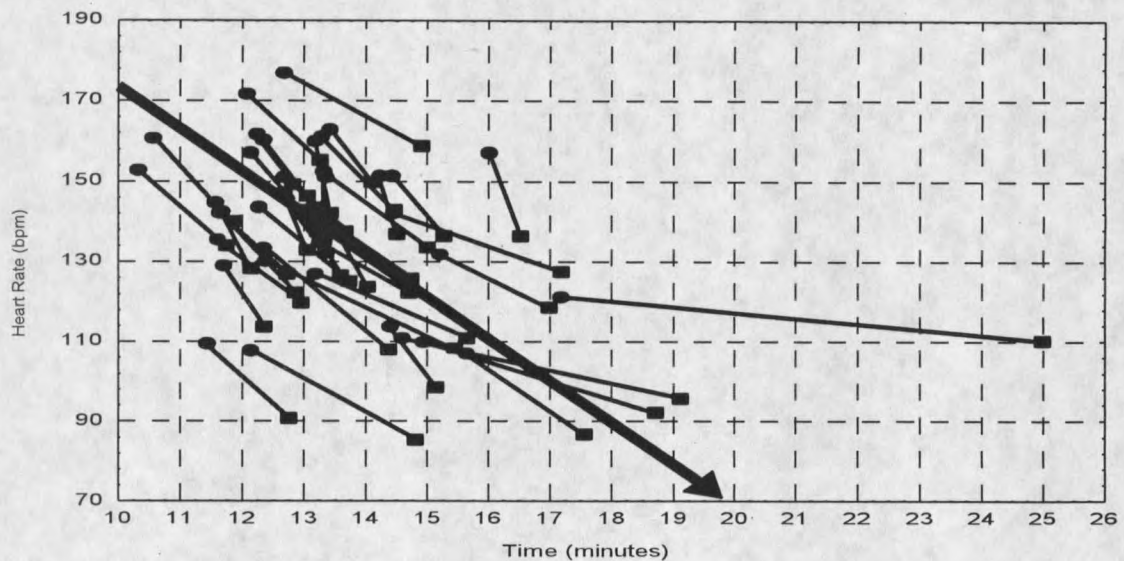


Figure 9. Heart rate versus walk time for the moderate and low intensity walk tests. Circles represent data from the moderate intensity walk test (RFTW₁₅). Squares represent data from the low intensity walk test (RFTW₃₀). The arrow represents the average change in the (heart rate/time) ratio seen with a change in walk intensity from moderate to low intensity (n=40).

CHAPTER FIVE

DISCUSSION

Introduction

Kline et al. (1987) validated the Rockport Fitness Walking Test on a group of adults between the ages of 30 and 69. Since the publication of this research in 1987, several studies have been performed to determine the RFWT's validity for young adults. Coleman et al. (1987) found the RFWT to accurately estimate $\dot{V}O_{2MAX}$ in adults between 20 and 29 years of age. However, Dolgener et al. (1994) and George et al. (1998) found the test to systematically overestimate $\dot{V}O_{2MAX}$ in young adults. The need to resolve these conflicting reports prompted this study. Thus, the primary purpose of this study was to determine whether the RFWT accurately estimates $\dot{V}O_{2MAX}$ in young adults (18-29 years).

Whereas, Kline et al. (1987) and Dolgener et al. (1994) instructed subjects to walk at the fastest pace that could be maintained, George et al. (1998) had subjects choose a "brisk" pace for the walk. Although the difference in walking speed may have resulted in an altered estimation of $\dot{V}O_{2MAX}$, it circumvented a major drawback associated with the RFWT. Because individuals are generally unaccustomed to walking at a maximal pace, the RFWT often elicits pain associated with the muscles in the anterior (Tibialis Anterior) and posterior (Gastrocnemius) portions of the lower leg. The omission of the required maximal walking pace would help to reduce this occurrence and therefore, allow a larger number of individuals to comfortably use the RFWT. Thus, the secondary purpose of this study was to evaluate the use of submaximal walking intensities during the RFWT.

 $\dot{V}O_{2MAX}$ Results

The results showed that the equation developed by Kline et al. (1987) underestimated $\dot{V}O_{2MAX}$ for young adults under all three walking conditions. These results do not support the findings of Dolgener et

al. (1994) and George et al. (1998) who found the generalized equation developed by Kline et al. (1987) to overestimate $\dot{V}O_{2MAX}$. In order to provide a means to accurately estimate $\dot{V}O_{2MAX}$ for young adults, Dolgener et al. (1994) developed several other prediction equations. However, the results of the current study identified significant differences between measured $\dot{V}O_{2MAX}$ values and those obtained using the Dolgener equation under all walking conditions. In fact, a systematic underestimation was observed. These results are similar to the findings of George et al. (1998), who cross-validated the generalized equation developed by Dolgener et al. (1994) that does not include age. A comparison between the studies was performed to identify possible causes for these differences. A difference between the studies in the subjects average $\dot{V}O_{2MAX}$ values may help explain the results.

The following discussion on regression will help to explain how differences in aerobic capacity can effect the predictive accuracy of an equation. This, in turn, resulted in the underestimation of $\dot{V}O_{2MAX}$. First, an example of the phenomena of regression will be given. Then, regression will be discussed as it pertains to the current study.

Figure 10 represents a normally distributed characteristic, where the population mean (Line A) lies at the center of the distribution. For this example, the characteristic represented by Figure 10 is body height. Line B represents a sample of individuals whose body height is above the population average.

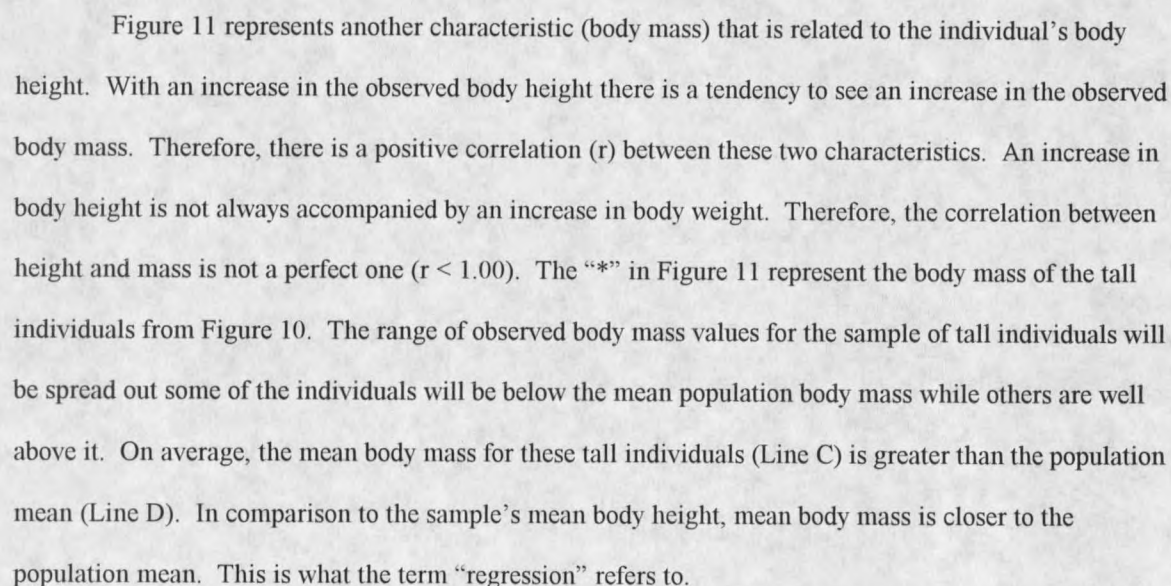
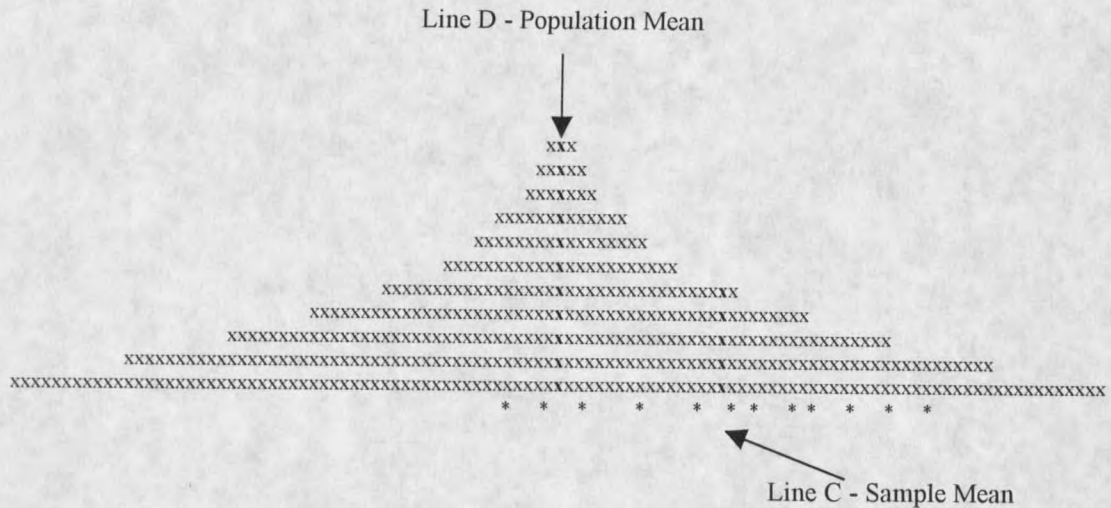
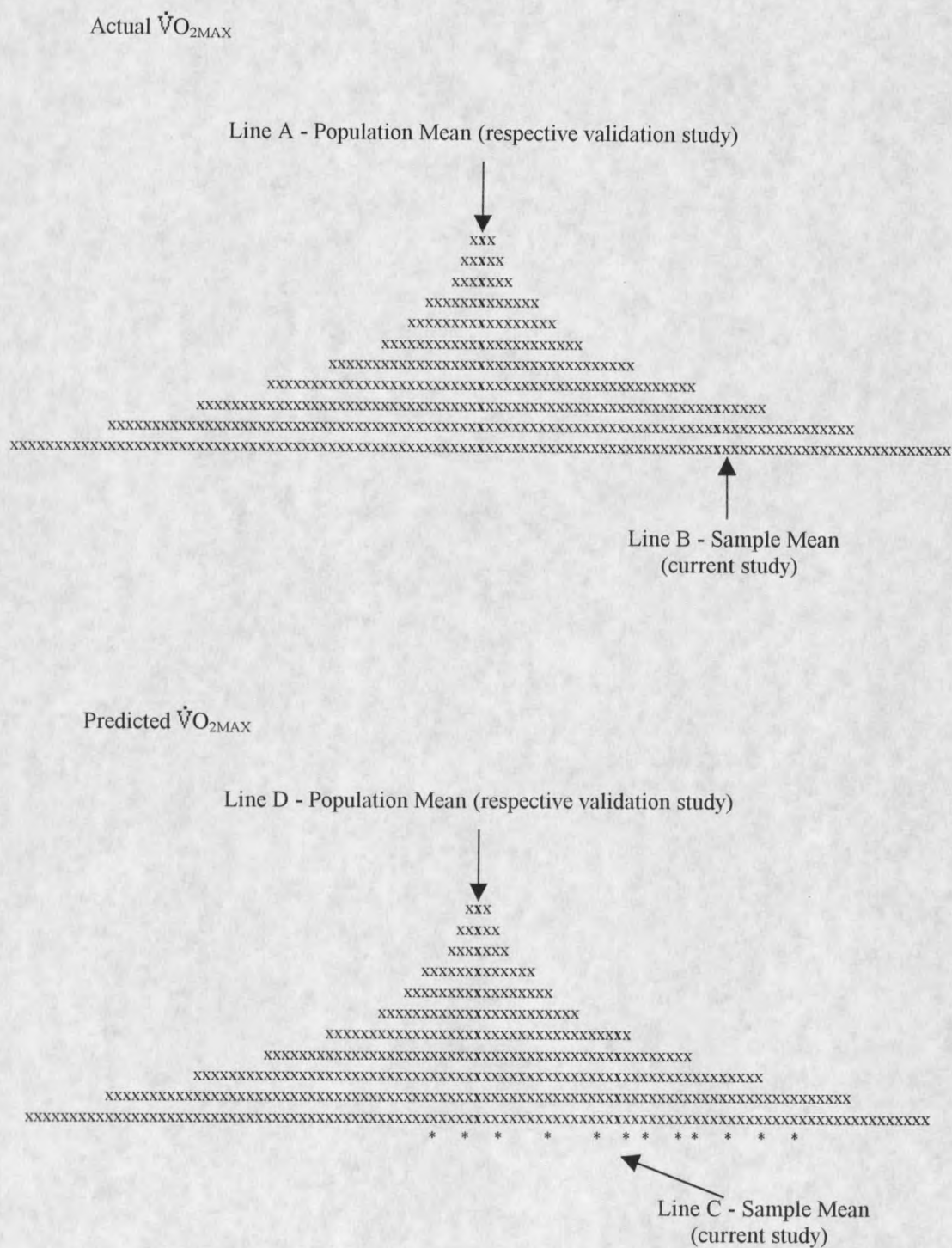


Figure 11. Body Mass Distribution



The phenomenon of regression was first noticed by Sir Francis Galton (1822-1891), a famous biologist, while studying the relationship between the height of fathers and their sons. Because the characteristics are positively correlated, the son of a tall father tended to also be tall, whereas the son of a short father tended to also be short (Devoure and Peck, 2001).

In the current study, the two related characteristics are the measured $\dot{V}O_{2MAX}$ values and the estimated $\dot{V}O_{2MAX}$ values. The measured $\dot{V}O_{2MAX}$ of the sample was, on average, well above that of the Kline and Dolgener studies. Thus, the related characteristic (estimated $\dot{V}O_{2MAX}$) is also above that of the samples of the respective studies. However, the regression resulted in the predicted values being closer to the mean predicted values of the Kline and Dolgener samples, respectively. The regression resulted in predicted $\dot{V}O_{2MAX}$ values that underestimated the measured $\dot{V}O_{2MAX}$. Figure 12 depicts the relationship between the actual and estimated $\dot{V}O_{2MAX}$ values.

Figure 12. Actual $\dot{V}O_{2MAX}$ versus predicted $\dot{V}O_{2MAX}$ 

Provided that information from the original validation study is known, Equation 3, listed below, will allow researchers to calculate the expected outcome when using an equation developed on a more or less fit group.

Equation 3

$$\dot{V}O_{2\text{MAX-REGRESSED}} = (\text{Measured } \dot{V}O_{2\text{MAX}} - \dot{V}O_{2\text{MAX-VM}}) (SD_{VP} / SD_{VM})(r_{XY}) + \dot{V}O_{2\text{MAX-VP}}$$

where the resulting value due to regression is represented by $\dot{V}O_{2\text{MAX-REGRESSED}}$; Measured $\dot{V}O_{2\text{MAX}}$ is the mean measured $\dot{V}O_{2\text{MAX}}$ for the subjects; $\dot{V}O_{2\text{MAX-VM}}$ stands for mean $\dot{V}O_{2\text{MAX}}$ of the group used to validate the equation; SD_{VP} is the standard deviation for the predicted $\dot{V}O_{2\text{MAX}}$ values of the validation group; SD_{VM} is the standard deviation for the measured $\dot{V}O_{2\text{MAX}}$ values of the validation group; r_{XY} is the correlation coefficient for the measured-predicted relationship in the validation group; and $\dot{V}O_{2\text{MAX-VP}}$ is the predicted mean $\dot{V}O_{2\text{MAX}}$ for the validation group (Lindquist, 1942).

Unfortunately, the published articles did not include adequate information for either the Kline or Dolgener generalized equations. However, data was available from the cross-validation group of the Kline study. The only information available from the Dolgener study was for the cross-validation of the generalized equation that does not include age as a predictor. In order to help account for the observed differences between measured and estimated $\dot{V}O_{2\text{MAX}}$ values, the cross-validation data from the Kline study was used with Equation 3 to calculate the expected values. The resulting values, referred to as "regressed $\dot{V}O_{2\text{MAX}}$ ", are the expected outcome when using the Kline equation (Equation 1) on subjects with the respective mean $\dot{V}O_{2\text{MAX}}$. Table 19, Figure 13, Figure 14, Figure 15, Figure 16, and Figure 17 compare the "regressed" to the estimated $\dot{V}O_{2\text{MAX}}$ values. A discussion of the table and figures will follow the identification of notable patterns and points of interest.

Table 19 compares the estimated $\dot{V}O_{2\text{MAX}}$ values from the generalized equation developed by Kline et al. (1987) to the regressed $\dot{V}O_{2\text{MAX}}$ values, which were calculated using the cross-validation data. For all three groups (males, females, and all subjects), there was no significant difference detected between regressed and predicted $\dot{V}O_{2\text{MAX}}$ for the RFWT_{MAX} and the RFWT₁₅. Analysis of data from the RFWT₃₀

revealed a statistically significant difference for the males ($P = 0.029$) and all subjects ($P = 0.045$). The difference for the female group approached significance ($P = 0.058$). The relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Kline equation for the $RFWT_{MAX}$ is depicted in Figure 13. The equation tends to slightly overestimate $\dot{V}O_{2MAX}$ for individuals with regressed $\dot{V}O_{2MAX}$ values greater than 50 ml/kg/min. Also, there appears to be one high leverage data point. Figure 14 depicts a comparison of the regressed and predicted $\dot{V}O_{2MAX}$ (Kline equation) for the $RFWT_{MAX}$ with the high leverage point removed. With the data point removed the least-squares regression more closely follows the line of identity. However, the removal of the point lowers the P-value from the ANOVA for all subjects from 0.9673 to 0.4033. The P-value for male subjects is also lowered (0.7909 to 0.5138). Figure 15 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987) for the $RFWT_{15}$. The least-squares regression line appears to closely coincide with the line of identity. No outliers or high leverage points can be seen. Figure 16 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987) for the $RFWT_{30}$. For most data points, the predicted $\dot{V}O_{2MAX}$ is less than the regressed data point. The line of identity and the least-squares regression line intersect at a $\dot{V}O_{2MAX}$ of 54 ml/kg/min. Also, there appears to be one high leverage point. Figure 17 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987) for the $RFWT_{30}$ with the high leverage point removed. The angle between the line of identity and the least-squares regression line is now smaller. However, with this data point removed the P-value for all subjects decreases from $P = 0.045$ to $P = 0.0060$.

Table 19, Figure 13 and Figure 14 show support for the use of the generalized equation developed by Kline et al. (1987) at maximal walking paces. Support for the "brisk" walking speeds is shown in Table 19 and Figure 15. College aged males typically have $\dot{V}O_{2MAX}$ values ranging from 44 to 50 ml·kg⁻¹·min⁻¹, whereas the typical college aged female has a $\dot{V}O_{2MAX}$ between 38 and 42 ml·kg⁻¹·min⁻¹. The male and female subjects in the current study had a mean $\dot{V}O_{2MAX}$ of 57.58 ml·kg⁻¹·min⁻¹ and 49.00 ml·kg⁻¹·min⁻¹, respectively. In comparison, the subjects in the Kline study had mean values of 42.2 ml·kg⁻¹·min⁻¹ and 31.4 ml·kg⁻¹·min⁻¹, for the males and females, respectively. Thus, the subjects in the current study

represent a group that is on average more fit than typical college aged individuals. However, even the typical college aged individual would be expected to have $\dot{V}O_{2MAX}$ values greater than those of the subjects in the Kline study. A possible solution to this problem is the development of a correction factor using Equation 3 and norm values from the 18 to 29 year old population. Unfortunately, the regression analysis does not help to explain how Coleman et al. (1987) was able to use the RFWT to accurately estimate $\dot{V}O_{2MAX}$ for a group of young adults (20-29 years) who were also highly fit (mean $\dot{V}O_{2MAX}$ of 49.5 ml•kg⁻¹•min⁻¹).

It has been stated that the near-linear portion of the heart rate- $\dot{V}O_2$ relationship begins around 110 bpm (Golding et al., 1989). For the RFWT₃₀, the mean heart rate was 125 bpm. However, there were eight subjects that displayed heart rates below 110 bpm. The equation developed by Kline et al. (1987) produced estimates of $\dot{V}O_{2MAX}$ that significantly differed from regressed $\dot{V}O_{2MAX}$ (Table 19). Furthermore, there was still a significant difference between regressed and predicted $\dot{V}O_{2MAX}$ following the removal of the eight subjects ($P=0.0255$). This indicates that the near-linear portion of the heart rate- $\dot{V}O_2$ relationship may actually begin above 110 bpm. The time measurements resultant from walking at a slow pace may also be a factor. However, although the time measurements change between different walking intensities, as long as the subject's heart rate is within the near-linear portion of the heart rate- $\dot{V}O_2$ relationship, the equation should still be able to accurately estimate $\dot{V}O_{2MAX}$. Figure 16 and Figure 17 depict a systematic underestimation of $\dot{V}O_{2MAX}$ during the RFWT₃₀. Thus, although there is no single explanation for the equation's inaccuracy, the results show no support for the use of slow walking paces during the walk test.

Table 19. Adjusted $\dot{V}O_{2MAX}$ vs. Kline equation predictions. Values are listed as mean $\pm$ standard error.

Measurement	Males (n = 20)	Females (n = 20)	All subjects (n = 40)
Measured $\dot{V}O_{2MAX}$	58.51 $\pm$ 1.84	49.57 $\pm$ 1.58	54.04 $\pm$ 1.40
Regressed $\dot{V}O_{2MAX}$	53.51 $\pm$ 1.41	46.63 $\pm$ 1.22	50.07 $\pm$ 1.07
Kline (Predicted $\dot{V}O_{2MAX}$) (P-value)	53.88 $\pm$ 1.55 (0.7909)	46.32 $\pm$ 0.94 (0.6184)	50.10 $\pm$ 1.08 (0.9673)
Kline 15 (Predicted $\dot{V}O_{2MAX}$) (P-value)	53.21 $\pm$ 1.06 (0.6929)	46.28 $\pm$ 1.17 (0.5809)	49.74 $\pm$ 0.96 (0.5034)
Kline 30 (Predicted $\dot{V}O_{2MAX}$) (P-value)	51.15 $\pm$ 1.29 (0.029 ^s)	43.56 $\pm$ 2.10 (0.058)	47.36 $\pm$ 1.36 (0.045 ^s)

Regressed = $\dot{V}O_{2MAX}$ values adjusted for differences in subject aerobic capacities (Equation 3); Kline = generalized equation for predicting $\dot{V}O_{2MAX}$ developed by Kline et al. (1987); 15 = walking test that was performed at 15% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; 30 = walking test that was performed at 30% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; r = Pearson Product Moment (correlation coefficient); E = total error; SEE = standard estimate of error; P-value from a two-factor, repeated measures analysis of variance; ^s = statistically significant difference ($\alpha=0.05$). $\dot{V}O_{2MAX}$ values are in units of $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

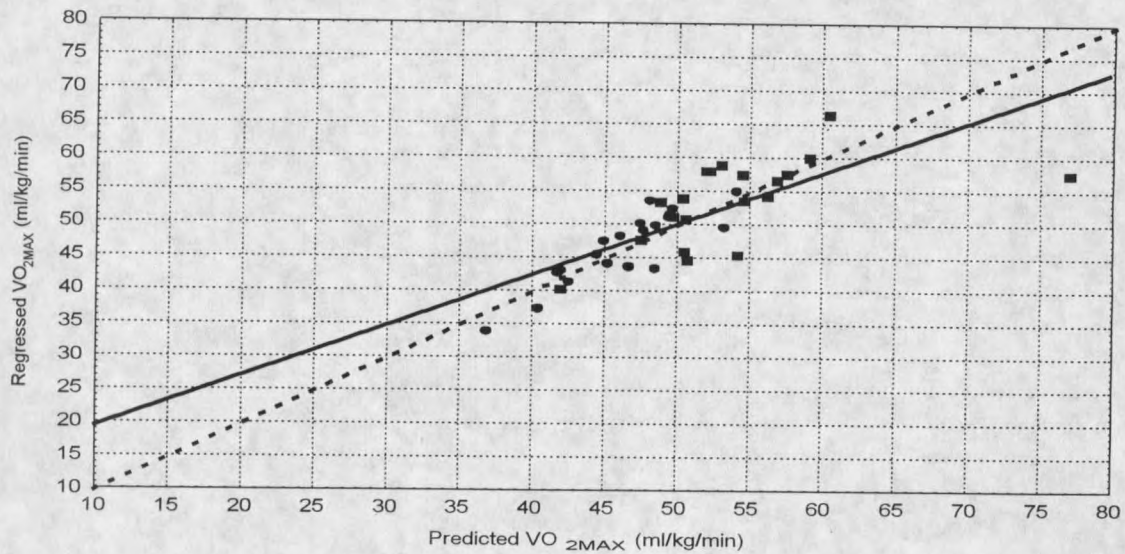


Figure 13. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the walking test performed at the subjects' fastest walking speed (RFTW_{MAX}). Circles represent females (n = 20); squares represent males (n = 20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

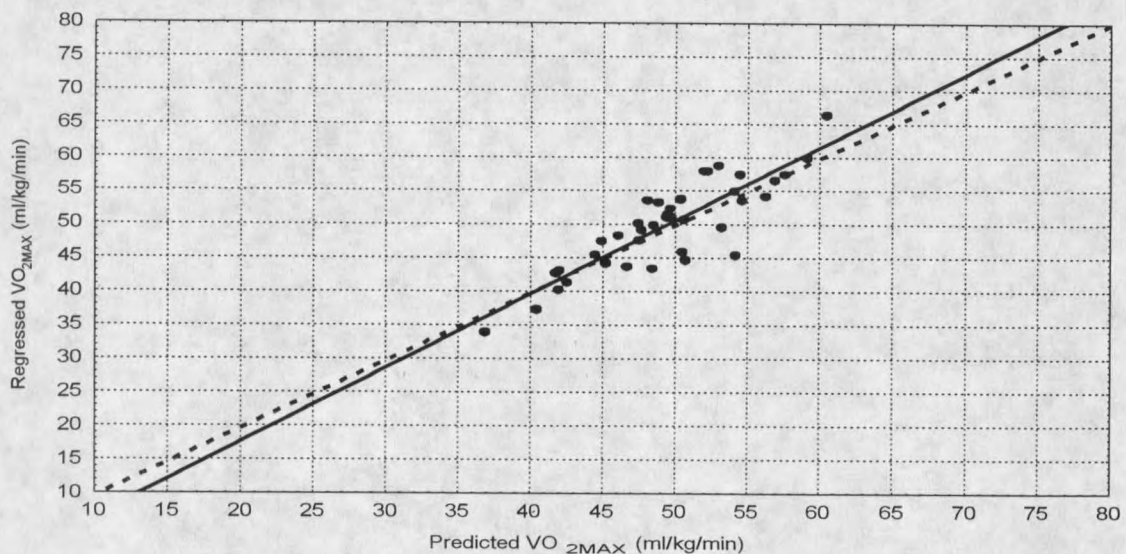


Figure 14. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). One high-leverage, data point was removed (n = 39). The data is from the walking test performed at the subjects' fastest walking speed (RFTW_{MAX}). Solid line is least-squares derived linear regression. Dashed line is line of identity.

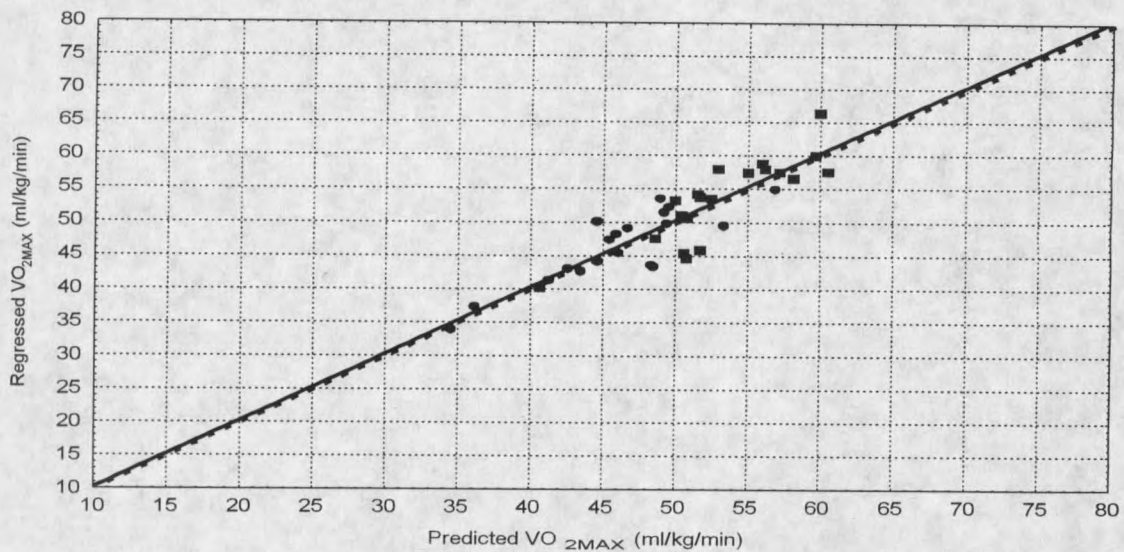


Figure 15. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the intermediate intensity, walking test. Circles represent females (n = 20); squares represent males (n = 20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

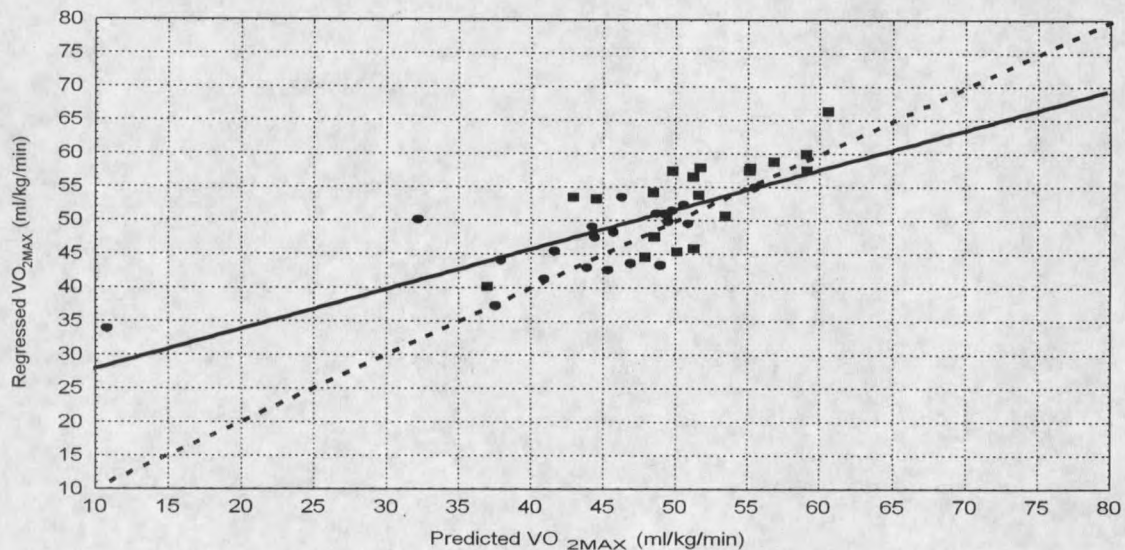


Figure 16. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). The data is from the lowest intensity, walking test. Circles represent females (n = 20); squares represent males (n = 20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

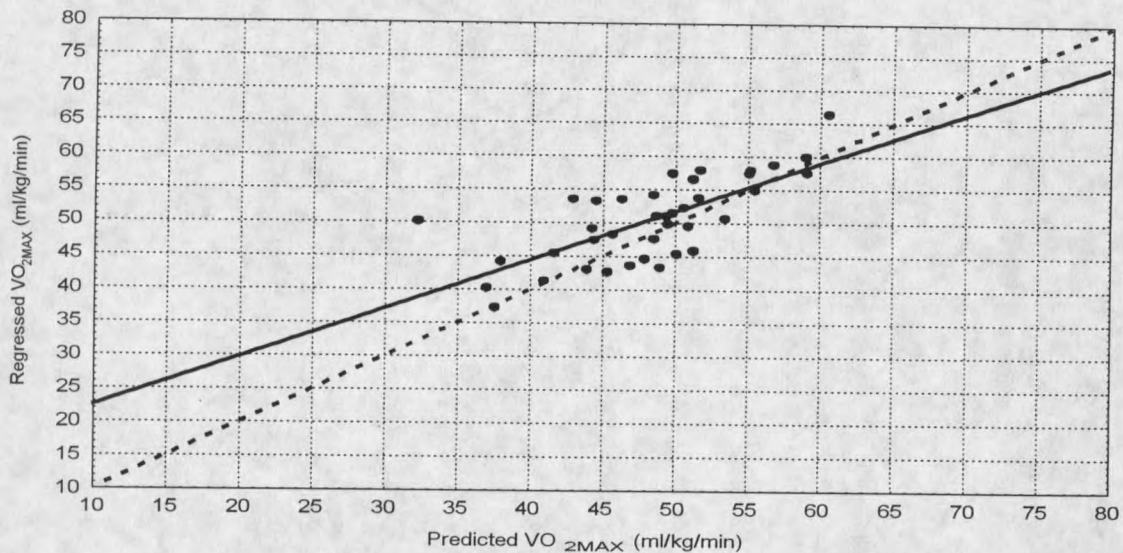


Figure 17. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Kline et al. (1987). One data point with high-leverage was removed ($n = 39$). The data is from the lowest intensity, walking test. Solid line is least-squares derived linear regression. Dashed line is line of identity.

In order to help account for the observed differences between measured and estimated $\dot{V}O_{2MAX}$ values, the cross-validation data from the Dolgener study was used with Equation 3 to calculate the expected $\dot{V}O_{2MAX}$ values. The resulting values are the expected outcome when using the Dolgener equation, that does not include age as an independent variable, on subjects with the respective mean $\dot{V}O_{2MAX}$. Table 20, Figure 18, Figure 19, and Figure 20 compare the “regressed” to the estimated $\dot{V}O_{2MAX}$ values. A discussion of the table and figures will follow their identification.

Table 20 compares the estimated $\dot{V}O_{2MAX}$ values from the equation developed by Dolgener et al. (1994) to the regressed $\dot{V}O_{2MAX}$ values. Regressed values were calculated using the cross-validation data. For the groups containing all subjects and males only, under all walking speeds, there were significant differences detected between regressed and predicted $\dot{V}O_{2MAX}$ ($P < 0.05$). However, under all conditions for the female group there were no significant differences detected. Figure 18 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) for the RFWT_{MAX}. For Figure 18, Figure 19 and Figure 20, the equation represented

is the Dolgener equation that does not include age as an independent variable. Figure 19 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) for the RFWT₁₅. Figure 20 depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) for the RFWT₃₀. There appears to be one high leverage data point. However, its removal does nothing for the equations predictive abilities for males.

Table 20, Figure 18, Figure 19, and Figure 20 show support for the predictive accuracy of the Dolgener equation for females only. Regardless of walking intensity, the equation tends to overestimate the regressed $\dot{V}O_{2MAX}$. This suggests that at least one problem, other than the subjects' fitness levels, is the cause of the equation's inaccuracy. One possibility is the equipment used in the study by Dolgener et al. (1994). Metabolic carts, although calibrated, may not necessarily give the same $\dot{V}O_{2MAX}$ values. Due to equipment expense, it is unlikely that most researchers are aware that this issue exists. Furthermore, this could help to explain how Dolgener et al (1994) found the generalized equation developed by Kline et al. (1994) to overestimate, rather than underestimate, $\dot{V}O_{2MAX}$ on group with higher $\dot{V}O_{2MAX}$ values. Considering that the regressed values of the females were accurately predicted, a new gender coefficient may help improve the predictive accuracy of the Dolgener equation. In addition, the difference in fitness levels also need to be accounted for. Therefore, it seems unlikely that the Dolgener generalized equation will ever be able to accurately estimate the $\dot{V}O_{2MAX}$ of young adults. George et al. (1998) also found the Dolgener equation to underestimate the measured $\dot{V}O_{2MAX}$. The underestimations were less than those observed in the current study. However, this could be due to fact that the subjects in the George study had slightly greater $\dot{V}O_{2MAX}$ values than those in the Dolgener study.

Table 20. Adjusted $\dot{V}O_{2MAX}$ vs. Dolgener equation predictions. Values are listed as mean $\pm$ standard error.

Measurement	Males (n = 20)	Females (n = 20)	All subjects (n = 40)
Measured $\dot{V}O_{2MAX}$	58.51 $\pm$ 1.84	49.57 $\pm$ 1.58	54.04 $\pm$ 1.40
Regressed $\dot{V}O_{2MAX}$	49.50 $\pm$ 0.93	44.98 $\pm$ 0.80	47.24 $\pm$ 0.70
Dolgener (Predicted $\dot{V}O_{2MAX}$) (P-value)	54.10 $\pm$ 0.59 (0.000 ^s)	44.34 $\pm$ 0.43 (0.263)	49.22 $\pm$ 0.86 (0.002 ^s)
Dolgener 15 (Predicted $\dot{V}O_{2MAX}$) (P-value)	55.21 $\pm$ 0.58 (0.000 ^s)	45.47 $\pm$ 0.47 (0.327)	50.34 $\pm$ 0.86 (0.000 ^s)
Dolgener 30 (Predicted $\dot{V}O_{2MAX}$) (P-value)	55.15 $\pm$ 0.64 (0.000 ^s)	45.14 $\pm$ 0.85 (0.778)	50.14 $\pm$ 0.96 (0.000 ^s)

Regressed = $\dot{V}O_{2MAX}$ values adjusted for differences in subject aerobic capacities (Equation 3); Dolgener = generalized equation for predicting $\dot{V}O_{2MAX}$ developed by Dolgener et al. (1994) that does not include age as a predictor; 15 = walking test that was performed at 15% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; 30 = walking test that was performed at 30% of heart rate reserve below average heart rate during the last two minutes of the maximally paced walking test; r = Pearson Product Moment (correlation coefficient); E = total error; SEE = standard estimate of error; P-value from a two-factor, repeated measures analysis of variance; ^s = statistically significant difference ($\alpha = 0.05$). $\dot{V}O_{2MAX}$ values are in units of $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

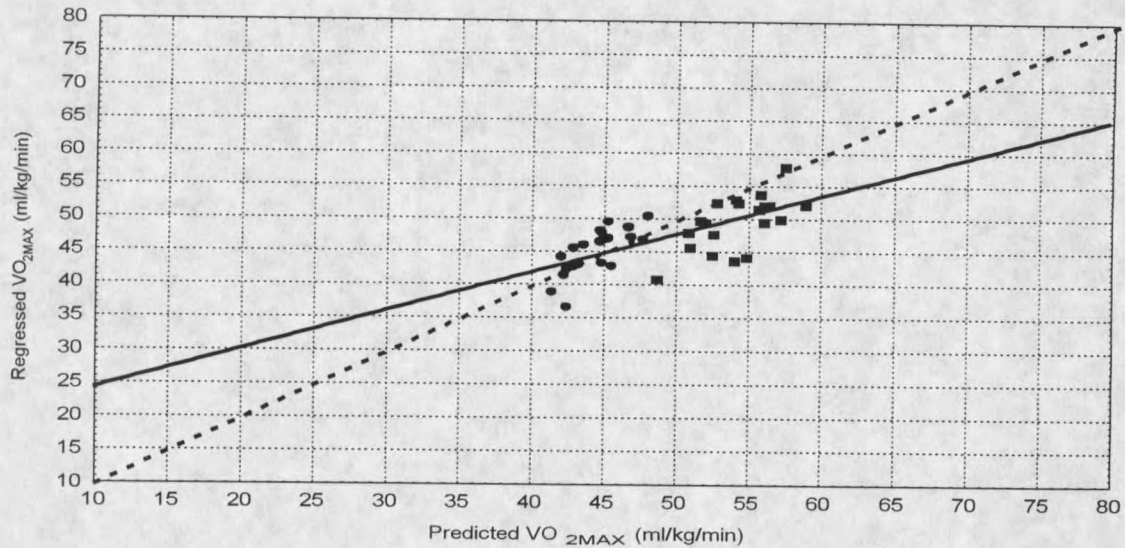


Figure 18. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) that does not include age as an independent variable. The data is from the walking test performed at the subjects' fastest walking speed (RFTW_{MAX}). Circles represent females (n = 20); squares represent males (n = 20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

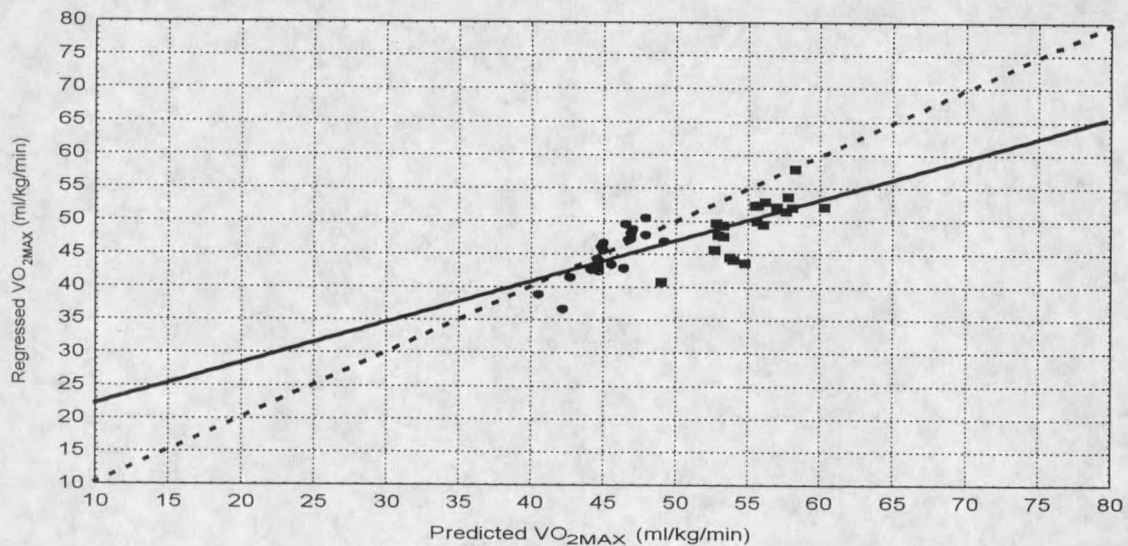


Figure 19. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) that does not include age as a variable. The data is from the intermediate intensity, walking test. Circles represent females (n = 20); squares represent males (n = 20). Solid line is least-squares derived linear regression. Dashed line is line of identity.

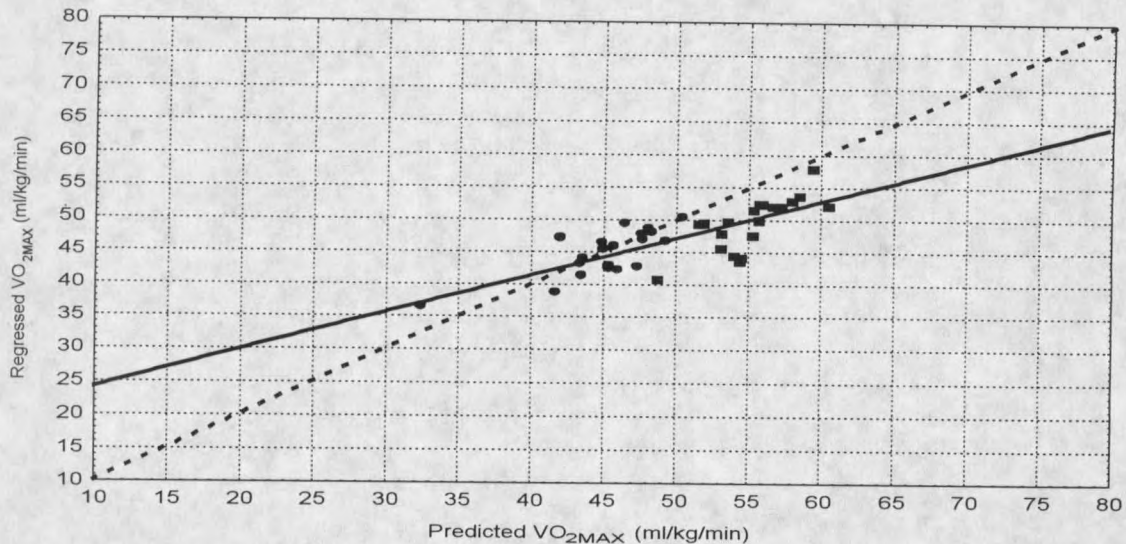


Figure 20. Scatterplot depicts the relationship between the regressed $\dot{V}O_{2MAX}$ and estimated $\dot{V}O_{2MAX}$ using the generalized equation developed by Dolgener et al. (1994) that does not include age as a variable. The data is from the lowest intensity, walking test. Circles represent females ($n = 20$); squares represent males ($n = 20$). Solid line is least-squares derived linear regression. Dashed line is line of identity.

Test-Retest Reliability

Analysis of the test-retest reliability showed no significant changes for the $RFWT_{MAX}$ and $RFWT_{15}$ (Table 14 and Table 15). However, there were significant differences seen in the data for the $RFWT_{30}$ (Table 16). For this test, there were differences found between body mass measurements ($P = 0.030$), walk completion times ($P = 0.015$), $\dot{V}O_{2MAX}$ estimates via the Kline prediction equation ($P = 0.010$), and $\dot{V}O_{2MAX}$ estimates via the Dolgener equation ($P = 0.013$). Since both equations use body weight/mass and time as predictors, it is not initially surprising to see significant changes in the estimations. However, the changes caused by the predictors resulted in opposite effects on the estimations. While the changes in body weight resulted in an average decrease of the estimates, the changes in walk time resulted in an average increase in the $\dot{V}O_{2MAX}$ estimates. Since the other predictors remained nearly unchanged from one trial to the next, it appears as though the dominant cause of changes in the predictions was due to the changes in time. In order to maintain a specific heart rate range, the intensity at which a person needs to walk may change from day to day. Observations of this phenomenon were made by several subjects and reported to the primary

investigator. If on the second trial the subject had to work at a greater intensity to stay within the heart rate range, then both the time to complete the walk and the estimations of $\dot{V}O_{2MAX}$ may be significantly changed. As for the changes in body weight, this could easily be accounted for by changes in hydration levels or possibly the result of a gradual weight loss program.

Subject Speed Comparisons

On average, the subjects were found to walk the fastest during the first lap of the RFWT_{MAX}. The mean speed for this lap was significantly faster than all other laps except 2, 3, and 12 (Figure 7). It is likely that after several laps the subjects were no longer making a conscience effort to walk as fast as possible, or they were pacing themselves to minimize lower leg pain. Later, when informed that they were on the last lap, they were again reminded that their goal was to complete the walk as fast as possible. Therefore, encouraging them to once again put forth a maximal effort regardless of pain or energy levels. An attempt was made to prevent this pattern by encouraging the subject to walk as fast as possible. The increase in walking speed observed during the last lap of the RFWT_{MAX} (Figure 7) is likely to have resulted in an increase in heart rate. This in turn, is probably the reason why post-exercise heart rate was greater than HR_{AVG} for the RFWT_{MAX} (Table 17).

On the subsequent walking tests (RFWT₁₅ and RFWT₃₀), the subject's heart rate was to be maintained within a specific range. For most subjects, a "brisk" pace quickly brought heart rate into the desired range for the RFWT₁₅. However, this technique to raise heart rate would likely place the subject's heart rate above the desired range after a lap or two. Thus, the subject would walk significantly faster for the first lap of the RFWT₃₀ (Figure 7). Furthermore, because the track required only 11½ laps to complete the one-mile walk, the first speed measurement was taken after walking for only ½ lap. Thus, it is likely the subject had not yet found an appropriate pace.

Heart Rate and Walk Time Comparisons

No significant differences were identified between post-exercise heart rate and HR_{AVG} for the $RFWT_{MAX}$ and $RFWT_{15}$ (Table 17). These findings are in agreement with those of Wilkie et al. (1987) who concluded that recovery heart rate is an acceptable replacement for average exercising heart rate during the last two minutes. The comparison of the data from the $RFWT_{30}$ revealed that a significant difference existed between the post-exercise heart rate and average heart rate. On average, subjects slowed down slightly during the last lap of this test (Figure 7). This could be part of the reason why the post-exercise heart rates were slightly lower than HR_{AVG} . Furthermore, with the exercise intensity being controlled by the heart rate monitor, the standard error of the heart rate measures was quite small. Therefore, there is a greater chance in detecting a statistical difference between the techniques. Regardless of the cause, on average, the difference between these techniques was 1.1 bpm. The difference between the estimations would be less than $0.20 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Therefore, although there was a statistically significant difference seen, it was not of a practical significance.

A comparison of the prescribed and HR_{AVG} values identified 12 test trials in which the HR_{AVG} values were not within the desired range. The desired ranges were assigned to ensure the subjects walked at three distinct intensities. ANOVAs performed that compared the heart rate and walk time values indicated that distinct walking intensities were established ($P < 0.05$).

A comparison of the walk time versus heart rate changes for the three walk intensities showed that an increase in walk intensity was associated with a decrease in the change in heart rate to walk time ratio. This indicates that as intensity decreases heart rate is less influenced than walk time. This may be a contributing factor for the inability of the equations to accurately estimate $\dot{V}O_{2MAX}$ under low intensity walking conditions.

CHAPTER SIX

CONCLUSIONS

Predictive Accuracy for Maximal Intensity Walking

The results from the current study indicate that neither the generalized equation developed by Kline et al. (1987) nor the generalized equation developed by George et al. (1994) accurately estimate $\dot{V}O_{2MAX}$ for highly fit, young adults (Tables 11, 12, and 13). The subjects in this study were, on average, more fit than those of the aforementioned studies and of typical college aged individuals. Although the subjects of the current study tend to be more fit than typical college-aged individuals, similar results would be expected if they were not.

Differences in fitness levels, between the validation group and the subjects of the current study, were able to account for differences between measured and estimated $\dot{V}O_{2MAX}$ values for the Kline equation (Table 19, Figure 13, and Figure 14). However, aerobic capacity differences did not explain the differences seen when using the Dolgener equation (Table 20 and Figure 18).

Predictive Accuracy for Submaximal Intensity Walking

If fitness levels are taken into account, submaximal walking intensities can provide accurate $\dot{V}O_{2MAX}$ estimates. However, this was found to be true only for the Kline equation at moderate walking intensities. Whereas the Kline equation was able to provide accurate estimates for the RFWT₁₅ (P-values = 0.50 to 0.69), it was not able to provide accurate estimates for the RFWT₃₀ (P-values = 0.03 to 0.06) (Table 19). Therefore, there appears to be a point in intensity at which the equation loses its ability to accurately predict $\dot{V}O_{2MAX}$. Thus, the use of the Kline equation should be restricted to maximal and "brisk" walking paces only.

Subject Heart Rate Comparisons

The comparison of heart rate values indicates that a significant difference between post-exercise heart rate and HR_{AVG} is possible (Table 17). Although the difference may reach a statistical difference, the resulting difference in the estimation would likely be considered insignificant in practical terms.

Implications for Further Research

Given the possible benefits of developing a submaximal walking test to estimate aerobic capacity, it would be of benefit for future studies to develop an equation to account for differences in mean $\dot{V}O_{2MAX}$ levels for the Kline equation. Further research is needed to determine the point at which the Kline equation loses its ability to provide valid estimates. If slower walking paces are found to provide valid estimates, this will help to further prevent pain associated with the anterior and posterior portions of the lower leg.

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APPENDICES

APPENDIX A
SUBJECT CONSENT FORM

**SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY**

PROJECT TITLE: Validity and reliability of the Rockport Fitness Walking Test using submaximal walking speeds.

PROJECT DIRECTOR: Christopher P. Keller
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PRINCIPAL INVESTIGATOR: Daniel P. Heil
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FUNDING: This study is not a funded project.

PURPOSE OF THE STUDY: The general purpose of this study is to determine whether different walking intensities affect the ability of the Rockport Fitness Walking Test (RFWT) to accurately estimate maximal oxygen uptake (VO_{2MAX}). The RFWT is a timed one-mile walking test developed for the estimation of VO_{2MAX} . The investigation will consist of six separate testing days. On all days, subjects are expected to wear clothing and footwear appropriate for exercise.

Visit #1: Documentation and VO_{2MAX} determination.

- **Prior to testing:** Upon arrival to the Movement Science Lab in Romney Gym, you will be asked to complete an Informed Consent Document and a medical history questionnaire. Following the review of these completed documents by the project director, your demographic data (height, weight, age, and gender) will be recorded. Next, you will be given as much time as required to perform a walking or running warm-up on the treadmill. You will then be fitted with a heart rate monitoring strap and a mouthpiece connected to the gas collection tube on the metabolic cart.
- **Testing:** You will select a walking or running speed on the treadmill to be used during the VO_{2MAX} test. Each stage of the test will have a two-minute duration. Treadmill grade will be set at 0% for the first stage and increased by 2.5% each stage thereafter. The test will be terminated when you have reached volitional exhaustion.

All of the RFWTs will be performed on the indoor track located in Shroyer Gym.

Visit #2: Maximally paced RFWT.

- **Prior to testing:** Upon arrival, you will have your body weight measured and then be fitted with a heart rate monitoring strap. You will then walk around the track for 10 to 15 minutes in order to warm-up.
- **Testing:** Testing will consist of walking for a distance of one-mile around the indoor track at the fastest pace that you can maintain. During the test, your heart rate will be measured and recorded by the heart rate monitor.

Visits #3, #4, and #5: Submaximal RFWTs.

- **Prior to testing:** Upon arrival, you will have your body weight measured and then be fitted with a heart rate monitoring strap. You will then walk around the track for 10 to 15 minutes in order to warm-up.
- **Testing:** The submaximal RFWTs will be performed at three distinct walking intensities. These will be at intensities less than that of the maximally paced RFWT. During each of the one-mile walking tests, you will be given a heart rate range to maintain. The watch for the heart rate monitor will be set to alarm if your heart rate is approaching the limits of the range. In response to an alarm you will be able to look at the watch to see if you should slow down or speed up.

Visit #6: This visit will be used to repeat one of the RFWTs.

- On the sixth visit, you will repeat one of the previously performed RFWTs for the purpose of assessing reliability.

POTENTIAL RISKS: As with any type of exercise testing there are potential risks. VO_{2Max} testing may cause extreme fatigue immediately after the test and possibly during the next day. Those who are less accustomed to high-intensity aerobic exercise are likely to experience extreme fatigue immediately after the test. VO_{2MAX} testing also involves a chance of precipitating a cardiac event (such as abnormal heart rhythms) or even death. However, the possibility of such an occurrence is slight (less than 1 in 10,000); since you are in good physical condition with no known symptoms of heart disease, and since the test will be directed by trained personnel. The measuring devices (heart rate monitor and mouthpiece) may feel somewhat restricting and/or uncomfortable during testing, but all possible adjustments will be used to achieve the greatest comfort for you. There is also the possibility of falling off the treadmill during the test. However, all possible precautions will be taken to ensure your safety and make you feel comfortable before any testing takes place.

BENEFITS: You will receive a full copy of your VO_{2MAX} test results. Usually our lab charges \$100 to perform this test. You will also receive copies of the Rockport Fitness Walking Tests results. In addition, you can obtain a summary of the study findings after the completion of the study by contacting Chris Keller at 586-4305.

CONFIDENTIALITY: The data and personal information obtained from this study will be regarded as privileged and confidential. They will not be released except upon your written consent. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each subject's data.

FREEDOM OF CONSENT: You may withdraw consent in writing, by telephone, or in person with the project director, Christopher Keller (406-586-4305), and discontinue participation in the study at any time and without prejudice or loss of benefits (as described above). Participation is completely voluntary.

In the UNLIKELY event that your participation in this research results in physical injury to you, the project director will advise and assist the participant in receiving medical treatment. In addition, Montana State University will not be held responsible for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science Laboratory. Further information regarding medical treatment may be obtained by calling the project director, Christopher Keller, at 406-586-4305. You are encouraged to express any questions, doubts, or concerns regarding this study. The investigator will attempt to answer all questions to the best of his ability. The investigator fully intends to conduct the study with your best interest, safety, and comfort in mind. Additional questions about the rights of human subjects can be answered by contacting the chairman of the Human Subjects Committee, Stephen Guggenheim, at 406-994-4411.

STATEMENT OF AUTHORIZATION

I have read the above and understand the discomforts, inconvenience and risks of this study. I, _____ (name of subject), agree to participate in the research described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____
Subject's Signature

Date: _____

Witness: _____

Date: _____

Investigator: _____
Christopher Paul Keller

Date: _____

APPENDIX B

SUBJECT DATA AND TEST RESULTS

Table 21. Subject characteristics data table.

Subject Number	Gender	Age (years)	Body Mass (kg)	Body Height (cm)	$\dot{V}O_{2MAX}$ (ml·kg ⁻¹ ·min ⁻¹)
1	Female	21	62.20	165.10	58.54
2	Female	22	60.95	162.56	50.64
3	Female	21	68.55	177.80	45.35
4	Female	23	52.44	164.15	48.04
5	Female	22	72.19	168.91	42.67
6	Female	24	51.98	155.89	60.42
7	Female	23	59.93	162.56	56.96
8	Female	21	67.65	163.83	55.31
9	Female	22	53.91	161.61	51.70
10	Female	21	59.25	163.20	45.72
11	Female	23	67.08	160.66	44.91
12	Female	21	59.93	166.69	53.35
13	Female	24	56.07	155.89	46.35
14	Female	24	71.73	174.63	44.41
15	Female	18	75.82	171.13	37.47
16	Female	27	75.59	133.67	33.06
17	Female	21	56.86	160.66	55.92
18	Female	21	62.20	162.88	52.78
19	Female	24	81.15	171.13	54.10
20	Female	21	63.11	170.18	53.71
21	Male	23	68.10	175.90	62.51
22	Male	29	96.25	191.45	63.58
23	Male	20	76.05	174.63	58.51
24	Male	19	99.09	189.23	47.95
25	Male	22	100.79	181.93	58.20
26	Male	23	87.85	177.80	55.32
27	Male	29	76.50	167.64	46.96
28	Male	22	81.72	195.58	58.90
29	Male	24	69.01	169.23	54.86
30	Male	23	68.89	183.83	75.19
31	Male	29	88.08	183.52	64.29
32	Male	24	112.02	174.63	41.24
33	Male	23	64.01	163.20	59.40
34	Male	21	66.17	171.13	66.88
35	Male	27	87.17	184.47	50.84
36	Male	24	78.54	178.44	65.38
37	Male	25	81.04	182.88	64.26
38	Male	24	79.00	165.74	48.58
39	Male	26	83.54	185.74	63.75
40	Male	23	81.04	171.77	63.68

Table 22. Data table for the maximal intensity one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
1	62.65	12.41	163	163	48.06	43.99
2	62.20	12.20	185.625	186	44.91	41.42
3	68.44	12.05	162.167	161	48.40	44.33
4	51.98	12.31	194.833	200	44.46	40.15
5	72.64	13.19	168.917	171	42.52	40.68
6	52.44	10.33	171.905	174	54.05	45.97
7	59.13	12.03	160.042	159	49.61	44.71
8	67.08	11.29	173.292	177	49.37	43.84
9	53.80	12.62	178.667	182	46.04	41.88
10	59.25	11.50	194.75	194	46.65	42.19
11	66.51	13.67	166.416	165	41.98	40.76
12	60.38	11.76	146.333	153	53.19	46.38
13	56.98	13.36	160.333	160	45.19	42.30
14	71.39	13.08	172.583	172	41.76	40.20
15	76.05	13.81	175.542	168	40.43	41.03
16	75.25	15.62	139.083	138	36.86	38.70
17	57.32	12.33	161.583	173	49.45	43.41
18	62.65	12.07	172.833	172	47.63	43.51
19	81.61	12.88	129.5	129	47.40	44.61
20	63.11	11.99	168.708	168	48.47	44.06
21	68.10	11.81	148.042	153	56.89	53.37
22	98.52	11.16	130.042	131	54.46	52.57
23	77.63	13.33	128.625	124	54.60	54.48
24	99.43	12.26	132.75	130	54.15	54.06
25	104.19	12.60	147.292	146	48.80	50.32
26	87.62	11.54	179.25	182	49.68	48.94
27	76.95	12.42	151.375	153	50.67	49.78
28	81.72	11.77	179.04	177	50.34	49.94
29	70.26	12.62	167.5	168	50.54	49.89
30	68.55	10.96	143.167	148	60.46	55.34
31	87.17	10.98	160.417	160	52.20	50.46
32	110.66	14.14	147.083	150	41.95	46.20
33	64.01	13.20	128.2	127	56.25	54.49
34	65.38	10.95	160.208	165	59.13	54.31
35	88.87	11.79	176.875	177	47.48	47.71
36	79.22	11.55	164.583	161	52.98	51.70
37	81.95	10.97	177.75	177	51.95	50.24
38	81.95	11.77	173.417	170	50.43	50.09
39	84.10	10.71	128.417	127	77.01	55.91
40	82.86	10.44	156.833	155	57.58	54.20

Table 23. Data table for the moderate intensity one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
1	62.65	13.11	143.083	144	48.90	45.04
2	61.06	13.29	160.875	156	45.41	43.18
3	68.44	12.97	142.667	142	48.44	45.02
4	51.87	12.69	176.958	174	46.01	42.51
5	72.19	14.45	151.208	152	41.26	40.86
6	53.35	11.20	152.792	154	56.89	45.90
7	59.13	12.68	147.083	148	49.51	44.92
8	68.55	12.28	143.458	138	50.55	46.59
9	53.80	13.44	162.667	161	45.89	42.97
10	60.04	12.07	171.500	174	48.29	43.49
11	66.40	14.23	151.167	147	42.57	41.93
12	59.93	12.37	133.250	133	53.33	47.72
13	55.62	14.48	142.083	141	44.62	42.78
14	70.94	13.18	160.000	152	43.45	42.36
15	76.27	16.01	156.833	148	36.13	39.75
16	75.36	17.20	121.125	120	34.50	38.20
17	56.98	13.30	143.500	143	49.17	45.31
18	63.45	13.37	151.000	153	46.67	43.52
19	82.06	14.62	110.958	107	44.56	44.29
20	65.26	12.72	145.542	145	49.35	45.34
21	66.97	12.38	130.042	131	58.15	55.13
22	96.93	12.15	107.667	106	55.00	53.97
23	77.18	14.93	109.875	105	52.42	54.12
24	97.16	14.39	113.792	113	50.56	52.76
25	104.87	13.20	126.958	127	49.91	51.47
26	88.08	12.68	150.792	150	50.33	50.73
27	76.05	13.25	134.750	137	50.70	50.35
28	81.04	12.24	161.667	162	51.64	50.96
29	69.46	13.31	152.5	154	50.76	50.45
30	70.48	11.71	128.792	131	59.94	55.92
31	87.40	11.63	142.208	140	52.89	51.68
32	111.68	15.22	131.750	133	40.62	46.31
33	64.47	15.65	107.042	110	51.48	52.44
34	64.70	11.68	142.417	140	59.65	56.05
35	87.28	12.34	160.167	157	48.57	49.25
36	79.11	11.59	144.625	143	55.98	53.70
37	80.59	10.56	160.708	160	56.19	52.97
38	82.40	12.16	156.830	154	51.67	51.26
39	83.08	11.45	109.250	107	60.53	57.08
40	82.40	11.62	135.292	133	57.19	54.86

Table 24. Data table for the low intensity one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
1	63.11	14.73	125.875	125	46.24	44.57
2	61.29	14.47	142.625	142	44.39	42.87
3	68.55	13.60	126.333	127	48.92	45.71
4	51.98	14.90	158.833	156	41.63	41.00
5	71.96	15.28	136.250	136	40.94	41.37
6	52.10	11.74	133.750	137	55.47	47.95
7	59.13	13.04	132.792	135	50.55	45.82
8	68.55	13.75	124.958	123	48.67	45.94
9	54.03	14.11	149.833	146	45.66	43.58
10	60.84	13.25	155.167	154	46.86	43.82
11	66.85	14.49	136.792	134	43.89	42.96
12	59.25	14.36	108.167	109	50.86	47.31
13	55.96	17.20	127.625	126	37.94	40.07
14	71.96	13.42	142.167	138	45.30	43.50
15	76.73	16.53	136.583	132	37.55	40.71
16	75.02	25.01	110.083	108	10.81	26.99
17	57.89	14.04	123.458	122	49.73	46.44
18	62.65	14.99	133.500	135	44.25	43.03
19	82.86	19.11	95.500	93	32.17	38.56
20	64.92	13.35	132.125	130	49.46	46.08
21	69.01	15.45	108.250	111	51.17	52.28
22	97.38	14.80	85.333	85	49.74	52.04
23	77.18	18.70	91.875	94	42.91	49.28
24	99.99	15.14	98.250	97	50.06	53.14
25	104.65	15.64	110.792	112	44.51	49.26
26	87.17	13.66	137.625	137	49.34	50.70
27	76.50	14.70	122.250	122	47.85	49.68
28	81.72	12.83	149.333	148	51.55	51.57
29	69.46	13.33	135.208	137	53.42	52.37
30	68.33	12.36	113.667	115	60.53	56.87
31	87.62	12.73	126.917	124	51.66	51.72
32	111.12	17.01	118.583	114	36.95	45.65
33	64.47	17.56	86.667	86	48.44	52.11
34	64.47	12.84	122.292	120	59.04	56.48
35	86.83	13.04	146.500	145	48.48	49.52
36	79.00	12.14	128.167	121	56.78	55.34
37	80.36	11.88	139.900	142	55.17	52.92
38	82.06	13.23	137.583	139	51.23	51.26
39	83.31	12.77	90.750	89	59.09	57.00
40	83.08	12.97	119.833	114	55.08	54.80

Table 25 Data table for the maximal intensity repeat one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
1	61.86	12.55	165.96	162	47.30	43.95
3	67.87	12.12	163.667	166	48.03	43.69
6	51.98	9.59	177.625	180	55.62	46.50
8	67.31	11.04	176.416	182	49.67	43.66
9	53.00	12.39	173.792	167	47.69	44.04
16	75.36	16.87	140.375	137	32.56	36.78
18	63.33	11.89	168.875	168	48.74	44.21
23	76.73	13.25	127.083	123	55.27	54.80
24	99.43	11.60	155.833	156	52.69	52.14
32	111.57	14.04	141.125	143	43.04	47.08
33	64.24	13.40	127.875	128	55.59	54.03
34	64.92	10.21	178.833	180	58.71	53.83
35	88.08	11.80	170.083	170	48.63	48.56
38	82.17	11.27	166.958	168	53.03	51.11

Table 26 Data table for the moderate intensity repeat one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
2	61.97	12.84	161.875	158	46.57	43.61
4	52.21	12.61	176.542	175	46.31	42.51
7	60.27	13.01	149.000	144	47.92	44.74
10	61.86	12.29	172.625	173	47.10	43.11
14	72.87	13.21	157.000	162	43.52	41.02
17	56.52	12.93	138.417	140	51.26	46.29
22	95.11	11.87	107.458	105	56.24	54.68
26	89.32	12.46	155.417	160	50.13	49.84
27	76.95	13.08	132.875	133	51.40	51.00
28	80.70	12.39	163.375	163	50.95	50.63
30	71.28	11.02	126.958	118	62.34	58.46
31	86.60	11.65	144.167	142	52.64	51.48
37	80.36	11.07	160.333	160	54.64	52.17

Table 27. Data table for the low intensity repeat one-mile walk test.

Subject Number	Body Mass (kg)	Time (min)	HR _{AVG} (bpm)	HR _{POST} (bpm)	$\dot{V}O_{2MAX}$ (Kline) (ml·kg ⁻¹ ·min ⁻¹)	$\dot{V}O_{2MAX}$ (Dolgener)
5	72.53	15.57	134.292	135	40.20	40.97
11	66.40	14.36	136.833	135	44.38	43.09
12	60.61	13.99	108.792	109	51.75	47.80
13	55.84	15.14	125.500	121	45.03	43.99
15	76.39	16.59	132.292	130	38.06	40.86
19	81.38	17.57	93.208	93	37.80	41.17
20	64.35	12.91	130.292	121	51.26	47.85
21	67.19	13.87	110.583	114	56.28	54.64
25	103.06	14.45	110.208	110	48.77	51.56
29	67.65	13.59	137.333	133	52.54	52.55
36	78.09	12.25	127.667	124	56.66	54.89
39	83.31	12.40	89.000	93	60.55	57.13
40	81.61	11.87	122.917	121	58.44	55.89

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