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

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 (VO2max) in young adults and (b) to determine whether submaximal walking intensities could provide equally accurate estimates from the respective equations. VO2max was measured using a treadmill graded exercise test on 40 volunteers (20 males, 20 females) between the ages of 18 and 29 years. On tire 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 VO2max values. Under maximal intensity walking conditions, the estimates of VO2max from the Kline equation (50.10 + 6.84 ml.kg-1.min-1) and from the Dolgener equation (47.20 + 5.14 ml.kg-1.min-1) were significantly less than actual VO2max (53.29 + 8.50 ml.kg-1.min1) ($P<0.01$). Systematic underestimations were also found with the submaximal walking intensities ($P<0.01$). Estimations of VO2max were considered to be acceptable if within 4.50 ml.kg-1.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 V02MAX values of the subjects in the current study were above those observed by Kline et al. (1987) (36.5 ± 10.6 ml.kg-1.min-1) and by Dolgener et al. (1994) (40.3 ± 6.49 ml.kg-1.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 VO2max ($P=0.9673$ 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 VO2max (P<00.l). The findings of this study show neither the Kline nor the Dolgener equations provide acceptable estimates of VO2max in young adults. Following adjustments for fitness level, the Kline equation was able to provide acceptable estimates of VO2max at maximal and moderate walking intensities.

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Daniel P. Heil, PhD — Daniel P. Heil (Signature) — 8/20/02 Date

Approved for the Department of Health and Human Development

Ellen Kreighbaum, PhD — Ellen Kreighbaum (Signature) — 8/28/02 Date

Approved for the College of Graduate Studies

Bruce McLeod, PhD — Bruce R. McLeod (Signature) — 8-28-02 Date

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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 ml•kg^{-1}•min^{-1}) and from the Dolgener equation (47.20 $\pm$ 5.14 ml•kg^{-1}•min^{-1}) were significantly less than actual $\dot{V}O_{2MAX}$ (53.29 $\pm$ 8.50 ml•kg^{-1}•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 ml•kg^{-1}•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 $\dot{V}O2_{MAX}$ values of the subjects in the current study were above those observed by Kline et al. (1987) (36.5 $\pm$ 10.6 ml•kg^{-1}•min^{-1}) and by Dolgener et al. (1994) (40.3 $\pm$ 6.49 ml•kg^{-1}•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 if 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-VO_2 relationship (George et al., 1998). According to Golding et al. (1989), the near linear heart rate-VO_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

$$\mathbf{H_o:}\ \mu_M \neq \mu_K \neq \mu_D$$

H_a : μ_M will equal either or both μ_K and μ_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

$$\mathbf{H_o:}\ \mu_1 \neq \mu_2 \neq \mu_3$$

H_a : μ_1 will equal either or both μ_2 and μ_3

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

μ_2 and μ_2 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 is 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-Rhyming 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 that 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 $ml \cdot kg^{-1} \cdot min^{-1}$. 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 6	20.8 ± 1.1 21.2 ± 2.3	F F	37.5 ± 3.9 45.7 ± 4.0	2.9	----	0.569	--	--
	Recovery heart rate (Skubic-Hodgkins Test)	35 6	20.8 ± 1.1 21.2 ± 2.3	F F	37.5 ± 3.9 45.7 ± 4.0	3.5	----	0.412	--	--

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 VO_{2MAX} using cycle ergometry.

		Estimation							Cross-Validation	
Reference	Variables	N	Age	Gender	VO_{2MAX}	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 VO_{2MAX} from Astrand-Ryhming Nomogram	63	20-69	M/F	2.07 ± 0.74+	0.25+	----	0.884	--	--

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 4. Test protocols developed for estimating VO_{2MAX} using treadmill walking.

		Estimation							Cross-Validation	
Reference	Variables	N	Age	Gender	VO_{2MAX}	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 ± 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 ± 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 VO_{2MAX} 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.

		Estimation							Cross-Validation	
Reference	Variables	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 ± 0.52+	----	0.90	0.810*	15	0.90
	Age, RER, TV, and fat-free weight	36	42.0 ± 9.9	M	2.72 ± 0.47+	----	0.90	0.810*	13	0.90
Latin and Elias (1993)	Speed, percent grade, and heart rate	28 25	19-40	M F	4.26 ± 0.5+ 2.68 ± 0.4+	0.48	----	0.723	--	--
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.

		Estimation							Cross-Validation	
Reference	Variables	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.

		Estimation							Cross-Validation	
Reference	Variables	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 ± 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 VO_{2MAX} using distances greater than one-mile.

		Estimation							Cross-Validation	
Reference	Variables	N	Age	Gender	VO_{2MAX}	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 4.8 km run time	32	23.2 ± 3.9	M	48.0 ± 5.1	----	----	0.774 0.689	-- --	-- --
Oja et al. (1991)	2 km walk time, age heart rate, and BMI	34 28	20-65 20-65	M F	48.0 ± 5.1 48.0 ± 5.1	3.3 5.1	0.84 0.83	0.75 0.73	111 75	0.81 0.80

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.

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.

Procedures

Measurement 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–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 $ml \cdot kg^{-1} \cdot min^{-1}$) with an increase in treadmill grade. The highest oxygen uptake value, but within 2.5 $ml \cdot kg^{-1} \cdot min^{-1}$ 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 11½ 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 (WS_{SUBMAX}). Prior to these tests several calculations were made including the subject's standing heart rate reserve (HRR_{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 HRR_{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 $\dot{V}O_{2MAX}$ test was used as the HR_{MAX}. The HRR_{STAND} was then used to calculate a range of heart rates for two submaximal walking intensities. Percentages (15% and 30%) of HRR_{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 HRR_{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 ± 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 $\dot{V}O_{2MAX}$.

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)

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

Equation 2 (Dolgener generalized equation)

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

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 ml•kg^{-1}•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 ± standard deviation; parentheses denote the range of values observed.

	Males (n=20)	Females (n=20)	Total (n=40)
Age (years)	24 ± 2.8 (19-29)	22.2 ± 1.9 (18-27)	23.1 ± 2.5 (18-29)
Body Mass (kilograms)	82.58 ± 12.80 (64.24-111.41)	64.15 ± 8.35 (52.10-81.81)	73.37 ± 14.16 (52.10-111.41)
Body Height (centimeters)	177.04 ± 9.91 (155.58-195.58)	163.58 ± 8.89 (133.67-177.80)	170.18 ± 11.68 (133.67-195.58)
Maximum Heart Rate (beats/minute)	193 ± 8 (178-205)	199 ± 9 (181-216)	196 ± 9 (178-216)
$\dot{V}O_{2MAX}$ (ml•kg^{-1}•min^{-1})	57.58 ± 7.87 (41.10-73.27)	49.00 ± 6.89 (32.74-59.71)	53.29 ± 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 ($RFWT_{15}$). 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 ml•kg^{-1}•min^{-1}) and (3.67 to 5.00 ml•kg^{-1}•min^{-1}) for the Kline and Dolgener equations, respectively. Bias values ranged from (-2.92 to -4.92 ml•kg^{-1}•min^{-1}) and (-4.52 to -4.90 ml•kg^{-1}•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 ($RFWT_{15}$). 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 ml•kg^{-1}•min^{-1}) and (7.87 to 8.76 ml•kg^{-1}•min^{-1}) for the Kline and Dolgener equations, respectively. Bias values ranged from (-1.81 to -5.00 ml•kg^{-1}•min^{-1}) and (-4.48 to -5.51 ml•kg^{-1}•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 ($RFWT_{15}$). 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 $RFWT_{MAX}$. 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 $RFWT_{15}$ 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 $RFWT_{30}$. 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 $RFWT_{MAX}$. The relationship between the measured $\dot{V}O_{2MAX}$ and the predicted $\dot{V}O_{2MAX}$ from the Dolgener equation for the $RFWT_{15}$ 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 $RFWT_{30}$. In Figures 4, 5, and 6 the Dolgener equation tends to underestimate $\dot{V}O_{2MAX}$. Furthermore,

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

Sample	Measurement Method (ml/kg/min)	VO_{2MAX} (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
Men	Actual VO_{2MAX}	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 VO_{2MAX} developed by Kline et al.; Dolgener = generalized equation for predicting VO_{2MAX} 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(α=0.05).

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

Sample	Measurement Method (ml/kg/min)	VO_{2MAX} (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
Women	Actual VO_{2MAX}	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 VO_{2MAX} developed by Kline et al.; Dolgener = generalized equation for predicting VO_{2MAX} 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(α=0.05).

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

Sample	Measurement Method (ml/kg/min)	VO_{2MAX} (ml/kg/min)	r	E (ml/kg/min)	SEE (ml/kg/min)	Bias (ml/kg/min)	P-value
All Subjects	Actual VO_{2MAX}	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 VO_{2MAX} developed by Kline et al.; Dolgener = generalized equation for predicting VO_{2MAX} 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(α=0.05).