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Jung Min Lee
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To the Graduate Council:

I am submitting herewith a thesis written by Jung Min Lee entitled "Validation of the Cosmed Fitmate for predicting maximal oxygen consumption." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

David R. Bassett Jr., Major Professor

We have read this thesis and recommend its acceptance:

Dixie L. Thompson, Eugene C. Fitzhugh

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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VALIDATION OF THE COSMED FITMATE FOR PREDICTING MAXIMAL OXYGEN CONSUMPTION

A Thesis Presented for
the Master of Science
Degree
The University of Tennessee, Knoxville

Jung Min Lee
December 2008

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Without you all this would not have been possible.

ABSTRACT

The primary purpose of this study was to assess the validity of the Cosmed Fitmate (FM) in predicting maximal oxygen consumption (VO_{2max}), compared to the Douglas bag (DB) method. In addition, this study examined whether measuring submaximal VO_2, rather than predicting it, can improve upon the prediction of VO_{2max}. Thirty-two males and sixteen females (Mean ± SD: age 31 ± 10 yr, body mass 72.9 ± 13.0 kg, height 1.75 ± 0.09 m, BMI 23.4 ± 3 $kg \cdot m^{-2}$) volunteered to participate in the study. Each participant completed a submaximal and a maximal treadmill test using the Bruce protocol on two separate occasions. During the submaximal test, VO_{2max} was predicted using the FM, while during the maximal test VO_{2max} was measured using the DB method. The Cosmed Fitmate predicts VO_{2max} by extrapolating the linear regression relating heart rate and measured VO_2 to age-predicted maximum heart rate (HR = 220-age). This study also examined the validity of predicting VO_{2max} by using the ACSM metabolic equations to estimate submaximal VO_2. VO_{2max} values from the FM, the DB method, and ACSM prediction equations were analyzed using repeated measures ANOVA and linear regression analyses. The level of significance was set at $P < 0.05$ for all statistical analyses. There was no significant difference between VO_{2max} predicted by the FM (45.6 $ml \cdot kg^{-1} \cdot min^{-1}$, SD 8.8) and measured by the DB method (46.5 $ml \cdot kg^{-1} \cdot min^{-1}$, SD 8.8) ($p = 0.152$). The results of this study showed that a strong positive correlation ($r = 0.897$) existed between VO_{2max} predicted by the FM and VO_{2max} measured by the DB method, with a standard error of the estimate (SEE) = 3.97 $ml \cdot kg^{-1} \cdot min^{-1}$. There was a significant difference in VO_{2max} predicted by the ACSM metabolic equations (51.1 $ml \cdot kg^{-1} \cdot min^{-1}$, SD 7.98) and VO_{2max} measured by the DB method ($p = 0.01$). The correlation between these variables was $r = 0.758$ (SEE = 5.26 $ml \cdot kg^{-1} \cdot min^{-1}$). These findings suggest that the Fitmate is a small, portable, and easy-to-use metabolic

system that provides reasonably good estimates of VO_{2max}, and that measuring submaximal VO_2, rather than predicting it from the ACSM metabolic equations, improves the prediction of VO_{2max}.

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CHAPTER I
INTRODUCTION

Maximal oxygen consumption (VO_{2max}) is the criterion measure of cardiorespiratory fitness and an objective measure of the maximal ability of the aerobic (oxidative) system to supply energy during strenuous exercise (1, 2). Maximum oxygen consumption is dependent on the ability of the oxygen transport system to deliver blood, and the ability of the working muscles to take up and utilize oxygen in energy production. A clear link exists between oxygen consumption (VO_2) and cardiorespiratory fitness because oxygen delivery to tissues is dependent on the heart and sometimes lung function (3).

VO_{2max} testing measures how well an individual takes in, transports, and utilizes oxygen via the pulmonary and cardiovascular system. VO_{2max} is typically measured with a maximal, graded exercise test (GXT) and a metabolic measurement system. The VO_{2max} test is typically conducted in a laboratory setting with indirect calorimetric analysis of expired gases using computerized instrumentation (4). The determination of VO_{2max} can be made using a variety of exercise modes, provided that the body's large muscle groups are activated and the intensity and duration of effort are sufficient to maximize aerobic energy transfer (5). The cycle ergometer and treadmill are two of the most commonly used laboratory methods for determining maximal oxygen uptake.

Direct measurement of VO_{2max} can be expensive, technically difficult, time consuming, and it requires trained personnel and complex laboratory equipment (6, 7, 8, 9). In addition, risks such as sudden death, myocardial infarction, and abnormal blood pressure and heart rate responses exist, particularly in high risk populations (78). Furthermore, measurement of maximal oxygen uptake depends on having a motivated subject exercise to exhaustion (40). As a result of these concerns, submaximal exercise testing serves as an alternative to maximal testing in situations where direct measurement of VO_{2max} cannot be performed.

Estimating VO_{2max} has been shown to be beneficial for competitive athletes who are seeking to improve training and for the general population in various clinical settings who are attempting to improve physical fitness. Many submaximal exercise protocols have been developed that attempt to estimate VO_{2max} or simply to categorize an individual's aerobic fitness level. These methods commonly employ bench stepping, cycle ergometer, treadmill walking or running, and track walking or running.

The practical utility of VO_{2max} prediction tests may be evaluated on the basis of four considerations: 1) accuracy and validity of the prediction; 2) ease and convenience of the testing protocol; 3) relative risk of injury to the subject; and 4) generalized application to a broad population (10). A review of past research regarding VO_{2max} prediction tests indicates that many studies have provided no measure of the standard error of estimate (SEE) (15, 21, 23, 24, 27, 28, 31, 32, 35), or have failed to present cross-validation results (6, 11, 9, 16, 7, 19, 22, 23, 24, 25, 26, 27, 31, 32, 33, 35). Also, there are only a few well-controlled research studies validating the prediction of VO_{2max} using the linear regression approach utilizing heart rate (HR) and measured submaximal VO_2 (6, 11, 17, 40). Conversely, many studies have been done using a treadmill to predict VO_{2max} but most have attempted to predict VO_{2max} from variables such as time to walk a mile (19), time-to-exhaustion (42), or the % grade and speed at a certain workload (22).

Recently, the Cosmed Fitmate (FM), a small, easy-to-use, semi-portable, and accurate device (37), was developed for measurement of oxygen consumption. The FM is a hand-held device that does not measure CO_2 production; thus, its VO_2 estimate is based on the measurement of ventilation, the fraction of expired oxygen (F_EO_2) and HR (which, in turn, is used to estimate the RER, and hence the F_ECO_2). Nieman et al. (37) observed that mean oxygen consumption did not differ significantly between indirect calorimetry and Fitmate with the Bruce protocol during stage 1 (17.3 ±1.0 vs. 17.8 ±1.2 $ml \cdot kg^{-1} \cdot min^{-1}$), stage 2 (25.4. ±1.3 vs. 25.7 ±1.2 $ml \cdot kg^{-1} \cdot min^{-1}$), and stage 3 (36.8 ±1.9 vs. 36.7 ±2 $ml \cdot kg^{-1} \cdot min^{-1}$). Although the validity of the FM for measuring VO_2 has been previously established, its validity for predicting VO_{2max} with a submaximal Bruce protocol has not yet been evaluated.

Many of the current submaximal treadmill tests generally show a standard error of the estimate (SEE) range from 3.45 $ml \cdot kg^{-1} \cdot min^{-1}$ to 6.30 $ml \cdot kg^{-1} \cdot min^{-1}$ (40). Other submaximal treadmill tests are complicated, time consuming, expensive, and may require a skilled technician to operate and maintain the equipment. Since the prediction of VO_{2max} for quantifying aerobic capacity is gaining in popularity, validation of a simple, submaximal treadmill test that utilizes a portable metabolic system is needed. Thus, the purpose of this study was to examine the validity of a portable device (Cosmed Fitmate) that predicts VO_{2max} by examining the linear regression between HR and measured VO_2 and extrapolates to age-predicted maximal HR. The criterion measure in this study was VO_{2max}, measured by the Douglas bag method during a treadmill maximal GXT.

CHAPTER II
LITERATURE REVIEW

Maximal oxygen uptake (VO_{2max}) is widely accepted as the primary physiological variable that best defines cardiorespiratory fitness and functional aerobic capacity (6, 8, 11). Maximal oxygen consumption is measured by determining the highest rate of oxygen consumption (VO_{2max}) during strenuous, whole-body dynamic exercise. This process is dependent on the cardiorespiratory system's ability to absorb oxygen via the lungs, deliver oxygenated blood to the working muscle and the muscle's cells ability to utilize the oxygen in mitochondrial energy production (39).

Direct measurement of VO_{2max} requires motivation and the ability of the subject to deliver a maximal effort. Therefore, it is important that the subject be physically capable of a maximal effort. If the target population used in testing does not consist of highly motivated people who can exercise at moderate to high intensities, then attaining a true VO_{2max} could be difficult. As a result of this, there is sometimes a need to estimate VO_{2max} from submaximal testing to minimize physical discomfort, when there is lack of motivation by the subject in performing a maximal effort, or in the presence of health contraindications associated with the subject performing the VO_{2max} test (40).

In general fitness center laboratories, VO_{2max} is often estimated using submaximal tests such as the Bruce treadmill test (42) and YMCA cycle ergometer test (41). The VO_{2max} measured by submaximal tests is based on a linear relationship between heart rate and exercise workload with extrapolation to an assumed maximum heart rate (39, 40). Estimating VO_{2max} from a submaximal exercise test is dependent on several assumptions (41). The first involves the linear relationship between heart rate and oxygen uptake, up to and including maximum values. This assumption is generally met during various intensities of light to moderate exercise testing. The second assumption is that maximum heart rate among individuals within an age group is similar. The heart rate standard deviation is approximately ± 11 beats·min^{-1} about the average maximal heart rate for individuals of the same age (43). This could mean that a subject with an actual heart rate of 185 beats·min^{-1} would have their VO_{2max} overestimated if the heart rate-oxygen uptake line is extrapolated to 195 beats·min^{-1}. It is also important to consider that heart rate decreases with age. If an age correction factor is not taken into consideration then older individuals will consistently have their VO_{2max} overestimated. A third assumption is that oxygen uptake at a given workload is similar when an individual is tested several times. If oxygen uptake is estimated from different exercise workload on different occasions, then the predicted VO_{2max} may be in error due to the difference in effort. The variation among subjects in exercise economy during activities such as walking or cycling is thought to be no greater than ± 15% (43). For bench stepping the variation can equal about 10%. Any change in the testing protocol or procedure could produce noticeable differences in the metabolic cost between tests. A fourth assumption that is thought to be a significant factor in obtaining reliable test results is day-to-day variation found in heart rate for an individual. It is understood that even under the strictest and most standardized condition, variations in submaximal heart rate for any individual is approximately ± 5 beats·min^{-1} with day-to-day testing at the same workload (43). Within the limitations of these assumptions, VO_{2max} predicted from submaximal heart rate is reported to be within 10 to 20% of the person's actual VO_{2max} values (43).

Maximal Oxygen Consumption

Maximal oxygen consumption (VO_{2max}) is the accepted index of cardiorespiratory fitness and functional aerobic capacity (6, 8, 22, 40). It is defined by Powers and Howley (44) as "the greatest rate of oxygen uptake by the body measured during severe dynamic exercise, usually on a cycle ergometer or treadmill; dependent on maximal cardiac output and the maximal arteriovenous oxygen difference". It is one of the major factors affecting performance in any aerobic endurance activity, and it is generally measured in exercise and performance laboratories. However, the importance of cardiorespiratory fitness is not limited to athletes. High levels of cardiovascular fitness are associated with lower rates of cardiovascular disease and all-cause mortality (45). Typical values of VO_{2max} vary from < 20 $ml \cdot kg^{-1} \cdot min^{-1}$ for sedentary healthy individuals to > 80 $ml \cdot kg^{-1} \cdot min^{-1}$ for elite endurance athletes.

Physiological determinants of maximal oxygen consumption

Traditionally, there are two theories that have been used to identify the factors limiting an individual's VO_{2max}. The first, the central limit theory, argues that factors related to the cardiovascular and pulmonary systems are the primary limiting factors for maximal oxygen uptake (58). Examples of central limitations include pulmonary diffusing capacity, hematocrit level, and the maximum cardiac output. The secondary theory is that peripheral factors at the level of the muscle are the principal limitations to maximal oxygen consumption (121). Mitochondrial and capillary densities would be considered to be peripheral limitations. Although both of schools of thought have been valuable in helping to identify possible limitations, neither is now considered to be the single correct theory (56).

Pulmonary Limitation

Just as the circulatory system may limit oxygen delivery during heavy exercise, so can the respiratory system. As cardiac output increases, the mean transit time of the blood through muscle capillary beds decreases; this also holds true for the transit time of blood though the pulmonary capillaries. It is believed that the lungs do not supply enough oxygen to the blood because of the velocity of the blood through the pulmonary capillaries is high (48).

In normal individuals, the lungs perform their job adequately and are not the limiting factor. This is evident due to a high level of O_2 saturation of the blood as it leaves the pulmonary capillary during heavy exercise. In contrast, in an elite athlete the mean transit time is less because of a greater maximal cardiac output, and the lungs cannot saturate the blood with oxygen as it passes through the pulmonary capillaries. Dempsey and Powers et al. (47) confirmed that arterial desaturation occurs in elite athletes. Additional proof was provided by Powers et al. (48) who showed that a hyperoxic gas mixture increased the VO_{2max} of elite athletes but had no effect on the VO_{2max} of normal individuals. Due to these observations it is practical to assume that the lungs are not a limiting factor during heavy exercise, except in special cases such as elite athletes who can achieve a very high cardiac output, pulmonary patients who have impairments impacting O_2 diffusion, and high altitude mountaineers faced with lower PO_2(80).

Cardiac Output

Maximal cardiac output is a measure of the heart's ability to supply oxygen enriched blood to the periphery of the body. Cardiac output is typically ~5L/min at rest, and can increase fivefold or more during exercise (49, 50). Some researchers believe that the cardiovascular system is the limiting factor. Rowell (51) states that the attainment of maximal oxygen uptake requires that a sufficient fraction of the total muscle mass be utilized during exercise to ensure that VO_{2max} is limited by the capabilities of the cardiovascular system. The cardiovascular system may be a limiting factor of maximal oxygen uptake, as shown by experiments analyzing the effects of active muscle mass on maximal oxygen uptake. It has been demonstrated that, in large muscle group activity, the capacity of the muscles to vasodilate (accepted blood flow) exceeds the cardiac output of the heart. In contrast, exercise performed using smaller muscle masses is limited by the vasolilation capacity of the working muscle and not cardiac output (52). This fact is demonstrated by experiments that involve the comparison of arm exercise and leg exercise. Researchers have found that VO_{2max} for combined leg and arm work was similar to that elicited by legwork alone (53). One would then think that if arm and leg-work were combined a much greater value for maximal oxygen uptake would be achieved than the value for either alone. However, this was not the case. Combined arm and leg work results in similar VO_{2max} values as leg-work alone (53, 54). Also, superimposing arm-work on high intensity leg-work reduced blood flow to the legs, thus decreasing oxygen uptake in the legs (55). This shows that cardiac output was not able to support the work being performed by the legs when the arms were added. Vasoconstriction of the leg vasculature had to occur in order to maintain arterial pressure.

Cardiac output has been shown to be one of the limiting factors in whole body VO_{2max}. This is shown by the fact that during maximal effort, nearly all of the oxygen supplied via arterial blood is consumed by the active muscle (47). Further proof of cardiac output as a limiting factor is shown by the fact that beta-blockers, which decrease maximal heart rate, decrease maximal cardiac output and consequently cause a decline in VO_{2max} (56).

Peripheral circulation

Astrand and Saltin’s 1961 paper discussed the factors limiting O_2 transport from air to tissue. The investigators hypothesized that peripheral factors set the limit, for example, the vascular bed in the working muscles or venous return to the heart (1). It is obvious that with training the capillaries in the muscle bed become more numerous; this increases the capacity for oxygen delivery, and decreases diffusion distance from the vessel to the mitochondria (57). So it is thought that the capillary density of the muscle bed can limit maximal oxygen uptake. However, the one-leg versus two-leg experiments disprove this hypothesis (55). In these experiments the VO_{2max} of one-leg exercise was determined, and it was thought that when another leg was included, the VO_{2max} of the active leg would be maintained. Instead, Klausen et al. (58) found that by employing more muscle mass, and consequently increasing the capillary density, actually decreased the VO_{2max} of the original leg in order to maintain blood pressure.

Skeletal Muscles

There is a significant increase in the number of mitochondria and the mitochondrial enzymes in the muscles with endurance training (57). The effects of these variables on VO_{2max} are discussed in a classic paper by Saltin and Gollnick (57). These researchers state that skeletal muscle adaptations play only a minor role in the improvement of VO_{2max}. They point to the fact that low-intensity training may cause an increase in mitochondria and mitochondrial enzymes without a corresponding change in VO_{2max}. They conclude that the skeletal muscle mitochondrial adaptations occur in order to allow that system to operate more efficiently and effectively. This is explained using the concept of Michaelis-Menten kinetics that high levels of enzymes in the system allow for greater activation of the system with a smaller disturbance (a lower work rate). The result is less lactate and a greater utilization of fat at a give work rate. An improvement in capillary density is also seen following training (57). However, the researchers note that the purpose of increase in capillary density is to increase the amount of time the blood spends in the capillaries, and therefore plays only a minor role in the increase of VO_{2max}.

In conclusion, while all of the above factors interact to determine an individual's VO_{2max}, it now seems that in normal individuals the cardiovascular system (cardiac output) is the principal limiting factor VO_{2max} (56). It appears that the work by Saltin (57) in 1983 provides the most convincing evidence of the factors limiting VO_{2max}. Saltin studied the effects of maximal effort in an isolated quadriceps group. The results showed that the isolated muscle demonstrated a VO_{2max} 2-3 times higher than the same muscle group during whole body exercise. Thus, the skeletal muscle has a tremendously high capacity for aerobic work, and the cardiovascular system, in particular cardiac output, must be the primary factor limiting VO_{2max}. More recently, it has been estimated that 70-80% of the limitation in VO_{2max} is due to cardiac output (56).

Maximal Oxygen Consumption (VO_{2max}) Test

VO_{2max} is commonly measured using a treadmill or cycle ergometer. These tests are usually continuous and incremental, in which the work rate changes every two to three minutes until the subject reaches volitional exhaustion. The reasoning for using such a rigorous test is that the results provide an indication of the body's maximal ability to deliver oxygen to the working muscles and the ability of the muscles to consume it (60). This test can be used as a diagnostic tool for cardiac problems and to evaluate treatment outcomes (61). Several protocols using treadmills and cycle ergometers have been developed for measurement of maximal oxygen uptake. Two common protocols that are used to determine VO_{2max} are the Bruce protocol, administered on the treadmill (42), and the Astrand cycle ergometer test (59). The results are typically expressed relative to the body weight ($ml \cdot kg^{-1} \cdot min^{-1}$) enabling the results to be compared with individuals of differing body masses. In addition, cycle ergometer and treadmill tests have been developed many other prediction equations that are manipulated to predict an individual's VO_{2max}.

Bruce protocol

The Bruce protocol (42) is a multistage treadmill test developed for use by those with possible coronary artery disease, but it is often used for the general population. The protocol begins with the participant walking at 1.7 mph with a 10% grade for 3 min for the first stage. The speed of the treadmill is set at 1.7 mph and is subsequently increased to 2.5 mph, 3.4 mph, 4.2 mph, 5.0 mph and 5.5 mph at 3-minute intervals throughout the test. The incline of the treadmill starts at 10% grade and increases by 2% every three minutes. The test increases in a similar manner but very few individuals reach the fifth stage and are considered to be unusually well-trained athletes. There are no rest intervals between the stages, and the participants move through the stages until they have reached an individually determined endpoint of volitional exhaustion.

Balke protocol

The Balke and Ware (83) exercise test protocol starts out at a treadmill speed at 3.4 mph and 0% grade during the first minute of exercise. The subject maintains a constant speed on the treadmill throughout the entire exercise test. At the start of the second minute of exercise test, the grade is increased to 2%. Thereafter, at the beginning of every additional minute of exercise, the grade is increased by only 1% until the subject reaches their VO_{2max}.

The prediction equation for the Balke test estimates the individual's VO_{2max} from exercise time. Alternatively, the researcher can use a nomogram developed for the Balke treadmill protocol to calculate the VO_{2max} of the subject. To use this nomogram, locate the time corresponding to the last complete minute of exercise duration the protocol along the vertical axis labeled "Balke time," and draw a horizontal line from the time axis to the oxygen uptake axis. The main criticism of the Balke protocol is that its duration is nearly twice as long as the Bruce protocol. However, compared to the Bruce protocol, the Balke protocol allows for a more gradual warm-up and is therefore safer (82). The Balke is basically an uphill walking test, whereas the Bruce protocol starts out as an uphill walking test and then in Stage 4 becomes an uphill running test.

Astrand-Cycle protocol

This cycle ergometer max test was developed in 1977 and utilized a cycle ergometer with the ability to manually increase the load by adding resistance. To begin, the subject performs one or two stages at submaximal loads, pedaling at a rate 50 revolutions per min (rpm). Those submaximal loads should elicit a heart rate of at least 140 $beats \cdot min^{-1}$ (bpm) for participants less than 50 years of age and 125 $beats \cdot min^{-1}$ for those individuals over 50 years of age. Then the load should be increased to a predetermined "supramaximal" load that is 10~20% higher than the predicted maximal oxygen uptake from the Astrand and Astrand nomogram (6). It was determined that if the participant could continue for 2 min at this load, even if a pedal rotation of 60 bpm is not kept, measurements during this time would correctly indicate VO_{2max} (59).

Treadmill versus Cycle Ergometer

Because the treadmill and cycle ergometer have both been used extensively to determine VO_{2max}, there has been discussion regarding which method provides a more valid measurement. McArdle et al. (14) evaluated this in their study comparing six of the more commonly used VO_{2max} treadmill and cycle ergometer tests. Their results showed significantly lower VO_{2max} measurements with cycle ergometers, ranging from 10.2 to 11.2% ($p < 0.01$). Another study (124) produced results of 50.7 ± 13 $ml \cdot kg^{-1} \cdot min^{-1}$ and 43.1 ± 11 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p = 0.001$) for treadmills and cycle ergometers, respectively. The 17.6% difference between the two tests confirmed the results of McArdle et al. (14). Other studies have identified this as well and suggested that the difference should be taken into consideration when deciding which VO_{2max}

protocols to use (39, 62). Cycling would be more appropriate for those who have been trained on a bike, but cycling would not be suitable for those who do not regularly ride a bike. A common complaint is a feeling of intense discomfort localized in their thighs (14). In the likely case that a participant does not train on a bike, it would be advantageous to use a treadmill protocol. Along with avoiding localized muscle fatigue in the legs, increased values of VO_{2max} would be observed. There are several other advantages to using a treadmill, one being that energy expenditure is constant and regulated by being able to set the speed of the belt. Secondly, the walking and running motions performed on a treadmill are more common than cycling (61, 93). In general, individuals reach higher VO_{2max} values during treadmill tests than they do with the cycle because of involvement of muscle mass.

Criteria for Achieving Maximal Oxygen Consumption

When an individual exercises with continuous, incremental workloads, he or she eventually reaches the point of exhaustion. With each increase in work rate, there is usually an increase in oxygen consumption. As volitional exhaustion is approached, many individuals can increase their work rate, while a leveling off in oxygen consumption is seen. This “plateau” in oxygen uptake with an increase in work rate has been proposed as a criterion for having achieved VO_{2max} (63). In 1923 Hill and Lupton study (64), the subject ran around an open-air grass track that was approximately 90 meters around. The subject carried a Douglas bag with a side pipe, a three-way tap, and a mouthpiece fitted with rubber valves. A timekeeper stood by calling out the time for each lap so the runner could adjust his speed to ensure steady state for a 30-second period of data collection. After data were obtained, the runner increased his speed in small increments until he could no longer maintain steady state. After the run, oxygen data was plotted against running speed. The researchers found “…the rate of oxygen consumption… increases as speed increases …reaching a maximum for speeds beyond 260 m·min^{-1}, however much the speed be increased beyond that limit, no further increase in oxygen intake occurred". This demonstrated that a plateau in oxygen consumption was reached even though higher levels of steady-state running could be achieved.

Despite this clear concept of plateau, it is not uncommon for subjects to complete a maximal graded exercise test (GXT) on a treadmill or cycle ergometer and fail to demonstrate a plateau in VO_2. An increase signifies a plateau on the treadmill in VO_{2max} of less than 2.0 ml·kg^{-1}·min^{-1} with 2.5% grade change (constant 7 mph speed) (56). Consequently, investigators tried to identify other variables that would indicate that the subject was working maximally when the highest uptake was measured in the last minutes of a GXT (63). These variables included the heart rate achieved during the graded exercise test, the post exercise blood lactate concentration, and elevated respiratory exchange ratio (RER).

Blood lactic acid is an indicator of the intensity of effort because levels of lactate are associated with muscle fiber recruitment (65), plasma epinephrine levels (66) and the reduction in liver blood flow (67) that occurs with exercise. To indicate a good effort by the subject, blood lactic acid should be measured at or above 8 mmol·l^{-1}. This value was then applied to those not achieving a plateau to validate their efforts. Even though there has been variation in the values of blood lactate indicative of a maximal effort, Astrand's work suggests a range centered around 8 to 9 mmol·l^{-1} (56).

The respiratory exchange ratio (RER) has been used as a secondary criterion for the achievement of VO_{2max} (63). In classic paper by Issekutz et al. (68), the authors mention that RER at heavy workloads is always above 1.0, and that value as high as 2.1 have been reported. In this study by Issekutz et al. (68), 32 untrained subjects exercised on a cycle ergometer until maximal oxygen was attained. Measurements during these maximal tests showed that "each subject, regardless of sex and age, reached the maximal O_2 uptake at about the same values of $\Delta RQ = 0.4$ (RQ 1.15)" (68). According to Howley et al. (63), "an $R \geq 1.15$ is not a universal finding, even in those who demonstrate a plateau in VO_2". However, this value is generally used to validate a maximal effort.

The achievement of some percentage of age-adjusted maximal heart rate has long been criticized because of the error of estimation (56). An individual's maximal heart rate can be estimated using the formula 220-age. However, the standard deviation associated with this formula is ± 11 bpm (63). Therefore, an individual whose maximal heart rate lies below the predicted value cannot reach the age-adjusted predict value during an exercise test. Because of the error involved, maximal heart rate cannot be considered accurate in validating a maximal effort (88). Nevertheless it is often used along with other criteria to assist in the validation of a measure of VO_{2max}. Researchers have used different guidelines to determine whether or not an achieved heart rate is suggestive of a maximal effort. These guidelines have included a heart rate at or above age-predicted maximal heart rate, 95% of the age-predicted value, or within 5 or 10 beats of the age-predicted values (56). No matter which guideline is used, there is considerable error involved with the use of heart rate as a criterion for VO_{2max}.

Using Submaximal Values to Predict VO_{2max}

Over the years there has been an increasing interest in the use of various submaximal exercise tests to predict aerobic fitness due to the risks involved with maximal grade exercise tests (GXT). It has been reported that there is a 3-fold increase in health risks associated with a maximal GXT when compared to a submaximal test (89). In addition, measurement of VO_{2max} with a maximal effort test is not always the most appropriate way to get an indication of maximum aerobic capacity. Sometimes it is simply too time consuming to run the tests if there are large numbers of subjects. Other reasons include eliminating the discomfort of bringing a subject to volitional fatigue, finding a well-equipped laboratory with the expense of skilled technicians, and reducing the chance of cardiovascular complications such as a heart attack occurring at high work load (11). For these reasons, a number of submaximal VO_2 test protocols have been developed to reduce or eliminate these complications.

Traditionally, the most common submaximal tests to predict VO_{2max} were based on the relationship of heart rate and VO_2 at one or more submaximal work rates, and extrapolation of the plotted line to maximal heart rate. The relationship between heart rate and oxygen uptake becomes nearly linear above approximately 110 beats$\cdot$min^{-1} (69). 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 (61). Many other predictive variables are also related to the heart rate and oxygen uptake relationship. For example, body mass is directly related to the amount of work required 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 be related to the heart rate and oxygen uptake relationship in some manner.

Step Test Protocols

One of the most commonly used field methods for estimating aerobic capacity is the single stage step test. Protocols using bench step test to estimate VO_{2max} are listed in Table 1. The single stage step test is popular because it does not require sophisticated, expensive

Table 1. Test protocols developed for estimating VO_{2max} using step testing.

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
Astand and Ryhming , 1954 (6)	18	18-19	M	4.03+	VO_2 and HR	---	---	0.28+
Skubic et al, 1963 (122)	27	11-24	F	---	Recovery HR (Harvard Step Test)	---	---	---
Michael et al, 1964 (123)	938	17-27	M	---	Recovery HR	---	---	---
deVries et al, 1965 (11)	16	20-26	M	50.5 ± 9.87	Recovery HR (Harvard Step Test)	---	0.587	6.35
"	16	20-26	M	50.5 ± 9.87	Recovery HR (Progressive Pulse Ratio Test)	---	0.506	6.93
Kurucz et al, 1969 (117)	30	19-56	M	2.58+	Recovery HR (OSU Step Test)	0.94	---	---
Mcardle et al, 1972 (14)	35 6	20.8 ± 1.1 21.2 ± 2.3	F F	37.5 ± 3.9 45.7 ± 4.0	Recovery HR (Queens College Test)	---	0.569	5.43
"	35 6	20.8 ± 1.1 21.2 ± 2.3	F F	37.5 ± 3.9 45.7 ± 4.0	Recovery HR (Skubic-Hodgkins Test)	---	0.412	4.08
Fox et al, 1973 (115)	135	17-32	M	44.8 ± 5.8	Recovery HR (Harvard Step Test)	---	---	---
Shapiro et al, 1976 (118)	63	17-19	M	46.1 ± 8.6	Recovery HR	0.809	---	---
Santa Maria et al, 1976 (113)	68	22.5 ± 4.12	M	45.4 ± 5.86	Recovery HR (OSU Step Test)	0.57	---	---
Jette et al, 1976 (13)	59	15-74	M/F	36.0 ± 10.4	Age, weight, Recovery HR, and VO_2	0.905	0.810	2.9
Tuxworth et al, 1977 (114)	45	23-41	M	2.65 ± 0.41	VO_2, wt, and HR	0.87	---	---
Fitchett, 1985 (98)	12	23-58	M	4.14 ± 0.68+	VO_2 and HR	0.84	---	---
Siconolfi et al, 1985 (116)	48	19-70	M/F	29.1 ± 7.6	Recovery HR	0.92	---	0.30+
Francis et al, 1989 (112)	17	19-33	F	43.4 ± 4.6	Recovery HR	0.74	---	---
Francis and Basher, 1992(12)	33	19-33	F	50.8 ± 9.1	Recovery HR	0.72	---	---

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; VO_2: oxygen consumption; SEE: standard error of estimate; "+"; liter·min^{-1}.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

equipment, and can be easily administered to large numbers of subjects. Brouha, Graybiel, and Heath (84) developed a simple single-stage step test, one of the most basic submaximal step test protocols with college-aged men at the Harvard Fatigue Laboratory. The researchers wanted to create a test that could classify fitness levels based on the post-exercise HR response. The subjects were required to step up and down on a 20-inch high platform, at a rate of 30 steps per minute, for five minutes. Subjects were then asked to sit down, and their recovery heart rates were measured after exercise. The researchers developed a performance scale, using the index score to reflect the individual's fitness levels. This test is still regarded as a good indicator of a generalized fitness level, but does not provide an estimation of VO_{2max}.

At one time, the most commonly used exercise test was the Master two step test (85). This test was constructed originally as an exercise tolerance test rather than a screening test for coronary artery disease. The subject walked up and over a device two steps high with three steps two of which were 9 inches above the floor and a top step 18 inches high. Even though Master used three steps in each ascent, two up and one down, it was called a two-step test. After going up and over, the patient then turned and walked over the steps again for a prescribed number of ascents.

The step test does not require expensive equipment, the step height does not have to be calibrated, everyone is familiar with the stepping exercise, and the energy requirement is proportional to body weight. The rate of stepping is established with a metronome, and the stepping cadence has four counts: up, up, down, down. The subjects must step all the way up and down in time with the metronome. This is a basic submaximal VO_{2max} test because it only consists of one stage. The disadvantage of step test protocols is that step height may cause local leg fatigue in shorter or heavier individuals. Several tests (6, 11, 12, 14) had low Pearson product-moment correlations (r) between predicted and measured VO_{2max} for the validation group. Moreover, several of the tests (6, 13) require the use of expensive equipment such as a metabolic cart. The only study that was validated using both male and female subjects was by Jette et al. (13). Thus many stepping protocols are limited by gender specificity and predictive accuracy.

Cycle Ergometer Test Protocols

The Astrand and Ryhming protocol used to predict VO_{2max} by use of a cycle ergometer is based on the linear relationship between HR and VO_2. Examples of cycle ergometer protocols for predicting VO_{2max} are listed in Table 2, including the popular YMCA cycle ergometer test. The original Astrand-Ryhming nomogram (6) was developed on data from 58 subjects aged 18 to 30 years who performed submaximal tests on a cycle ergometer and maximal tests on either a cycle ergometer or a treadmill. Astrand later tested 144 additional subjects and modified the nomogram to include an age-correction factor, because maximal HR decreases with age. One advantage of cycle ergometer test protocols is relatively safe positioning of the subject during a cycling test. On the other hand, a subject could easily fall with stepping and treadmill tests. In a cycle ergometer protocol the subject is already being supported by the cycle ergometer. The cycling test described by Astand and Ryhming (6) is one of the most frequently used submaximal cycle ergometer tests (70) and is still used today to predict VO_{2max}. However, an age correction factor is now included (ACSM 2001). Siconolfi et al. (9) improved the predictive accuracy of the Astrand-Ryhming nomogram by developing a different equation to adjust for age. This equation was shown to provide more accurate estimates of VO_{2max} compared to using the age-corrected Astand-Ryhming test. However, it is the age-corrected Astrand-Rhyming test (6) that is used by the American College of Sport Medicine. Although the test developed by

Table 2. Test protocols developed for estimating VO_{2max} using cycle ergometer

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
Astand and Ryhming, 1954 (6)	27 22 31 29	20-35	M F	4.11+ 2.87+	HR at 900 kpm HR at 1200 kpm HR at 600 kpm HR at 900 kpm	---	---	0.43+ 0.28+ 0.42+ 0.27+
deVries et al, 1965 (11)	16	20-26	M	50.5 ± 9.87	HR at 900 kpm (Astrand-Ryhming Nomogram)	---	0.587	---
"	16	20-26	M	50.5 ± 9.87	HR (Sjostrand Test)	---	0.506	4.75
Glassford et al, 1965 (96)	24	17-33	M	49.30 ± 10.72	HR at 600 kpm HR at 900 kpm	0.74	---	---
Mastropaolo et al, 1970 (94)	21	43-62	M	2.62+	WR, HR, BP, F_ECO_2, F_EO_2, VE, VO_2, VCO_2, and RQ	0.93	---	0.172+
Jessup, 1972 (15)	30	18-24	M	48.16 ± 5.46	HR	---	0.569	5.43
Fox, 1973 (48)	87	17-27	M	0.769	HR at 150W	0.76	---	3.39
Sicofolfi et al, 1982 (9)	63	20-69	M/F	2.07 ± 0.74+	Age and VO_{2max} from Astrand-Ryhming Nomogram	---	0.884	0.25+
Fitchett, 1985 (98)	12	23-58	M	4.14 ± 0.68+	VO_2 and HR	0.84	---	---
Storer et al, 1990 (104)	115	20-70	M/F	1.61 ± 0.39+	WR, wt, and Age	0.939	---	0.21+
Zwiren et al, 1991 (106)	38	30-39	F	44.8 ± 8.3	HR and WL	0.66	---	4.86
Latin et al, 1994 (105)	60	20-35	M/F	1.64 ± 0.16	WR and wt	0.96	---	0.11+
Hartung et al, 1995 (95)	37	19-47	F	2.39+	VO_2 and HR	0.72	0.52	0.34+
Greiwe et al, 1995 (101)	30	21-54	M/F	31.4 ± 8.2	HR, wr, and WL	0.86	---	0.40+
Swain et al, 1997 (100)	30	18-40	M/F	45.1 ± 1.5 33.4 ± 1.4	HR, VO_2 and RQ at 50 rpm	0.68	---	8.2
"	28	18-40	M/F	46.1 ± 1.6 33.1 ± 1.3	HR, VO_2 and RQ at 80 rpm	0.73	---	7.5
Lockwood et al, 1997 (103)	178	20-54	M/F	42.6 ± 0.8	HR and WL	0.80	---	1.8
McMurray et al, 1998 (16)	15 18	7-13	M F	48.1 ± 6.0 42.5 ± 6.7	HR and VO_2	---	0.651	4.1

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; FFM:fat-free mass; F_ECO_2: expired CO_2; TV: tital volume; BP: blood pressure; RQ: respiratory quotient; F_EO_2: expired oxygen; VO_2: oxygen consumption; VCO_2: expired CO_2 volume; SEE: standard error of estimate; "+"; liter·min^{-1}; WL: workload.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

Table 2. (concluded)

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
George et al, 2000 (99)	156	18-39	M/F	44.4 ± 6.5	Age, wt, HR, sex, and WL	0.88	---	3.12
Beekley et al, 2004 (97)	55 47	20-54	M F	48.3 ± 12.6 33.0 ± 10.0	HR (YMCA test)	0.79	---	8.9
Swain et al, 2004 (102)	50	18-44	M F	36.9 ± 8.8	VO_2 and HR	0.89	---	4.0

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; FFM:fat-free mass; F_ECO_2: expired CO_2; TV: tital volume; BP: blood pressure; RQ: respiratory quotient; F_EO_2: expired oxygen; VO_2: oxygen consumption; VCO_2: expired CO_2 volume; SEE: standard error of estimate; "+"; liter·min^{-1}; WL: workload.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

Siconofi et al. (9) provides a means to accurately estimate VO_{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. In addition, the protocol can elicit lower-extremity discomfort in some people, which may invalidate the results.

Treadmill Test Protocols

Protocols using treadmill walking and running to estimate VO_{2max} are listed in Table 3. Several submaximal treadmill walking protocols have been developed that estimate VO_2 using multiple linear regression (13, 17, 18, 90). Ebbeling et al. (18) developed a valid, time-efficient single stage protocol ($r_{adj} = 0.92$; SEE = 4.85 $ml \cdot kg^{-1} \cdot min^{-1}$) for males and females aged 20-59 years old. In addition, Town and Golding (90) developed a three-stage treadmill walk ($r = 0.84$; SEE = 4.08 $ml \cdot kg^{-1} \cdot min^{-1}$) for males aged 30-50 years old and Wilmore et al. (91) developed a four-stage treadmill walk ($r = 0.76$; SEE = 5.0 $ml \cdot kg^{-1} \cdot min^{-1}$) for males and females aged 18-30 years old. Furthermore, several of the researchers (8, 17, 21) 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 consumption (VO_2), expired carbon dioxide (CO_2), and respiratory exchange ratio (RER). Moreover, several protocols were validated using only males (17, 7, 21). The remaining protocols, which were developed using both genders and do not require expensive equipment, provide VO_{2max} estimation with high correlations to actual VO_{2max} (r between 0.84 and 0.96) (18, 20, 22, 19). Two of these treadmill test protocols (20, 18) included cross-validations. Whereas, Ebbeling et al. (18) validated the protocol on subjects between 20 and 59 years of age, George et al. (20) tested subjects between 18 and 29 years. Many of these treadmill protocols (22, 81, 93), including those developed by Ebbeling et al. (18) and George et al. (20),

Table 3. Test protocols developed for estimating VO_{2max} using treadmill walking and running.

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
Hermiston and Faulkner, 1971 (21)	36	34.0 ± 9.9	M	3.26 ± 0.52+	Age, HR, RQ, TV, F_ECO_2 and FFM	0.90	0.810	3.45
"	36	42.0 ± 9.9	M	2.72 ± 0.47+	Age, RQ, TV, and FFM	0.90	0.810	---
Metz and Alexander, 1971 (8)	30	12-13	M	50.88 ± 11.17	RQ and HR	0.701	0.491	3.125
Coleman, 1976 (7)	15	22.67 ± 1.8	M	4.49 ± 0.79+	Age, HR, and workload	---	0.706	0.45+
Town and Golding, 1977 (90)	20	30-50	M	51.38 ± 6.25	Age, load 3% grade, load 3, HR, resting HR, wt	0.838		± 4.079
Bonen et al, 1979 (17)	100	7-15	M	48.3 ± 5.1	VO_2, VCO_2, age, ht, wt and HR	0.62	0.384	4.1
"	100	7-15	M	1.77 ± 0.52+	VO_2, HR, ht, wt and age	0.95	0.903	0.17+
Mahar et al, 1985 (92)	--	44.8 ± 7.5		44.8 ± 7.35	VO_2 and HR	0.72		6.30
Montoye et al, 1986 (40)	367	10-39	M	---	HR and VO_2	0.72	---	3.7
Ebbeling et al, 1991 (18)	117	20-59	M/F	42.4 ± 12.9	Speed, HR, age, Speed*age, gender, and HR*age	0.96	0.923	4.85
"	36	42.0 ± 9.9	M	2.72 ± 0.47+	Age, RQ, TV, and FFM	0.90	0.810	---
Widrick et al, 1992 (19)	145	37.8 ± 10.4	M/F	42.0 ± 12.3	1-mile walk time, HR, gender, age, and wt	---	0.828	≤ 5.26
George et al, 1993 a (20)	66	18-29	M/F	48.3 ± 6.2	Speed, wt, gender, and HR	0.84	0.706	3.2
Latin and Elias, 1993 (22)	28 25	19-40	M F	4.26 ± 0.5+ 2.68 ± 0.4+	Speed, percent grade, and HR	0.85		0.48+
Swank et al, 2001 (93)	37	19 18	M F	41.6 ± 2.2 58.5 ± 2.4	HR, RER, and percent grade, speed	0.96	0.89	4.56
Linsey et al, 2008 (81)	34	18-55	M/F	47.9 ± 8.9	Speed, HR, age, Speed*age, gender, and HR*age	0.75	0.56	6.0

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; FFM:fat-free mass; F_ECO_2: expired CO_2; TV: tital volume; BP: blood pressure; RQ: respiratory quotient; F_EO_2: expired oxygen; VO_2: oxygen consumption; VCO_2: expired CO_2 volume; SEE: standard error of estimate; "+"; liter·min^{-1}; WL: workload.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

use treadmill speed and grade to predict $VO_{2max.}$ Unfortunately, treadmill speed calibration is rarely done outside of laboratory environment. Therefore, an additional source of error could be added.

Walking and Running Field Test Protocols

Walking and running tests are based on the time required to go a given distance or the total distance covered in a given time. The field type of test protocols was developed to estimate VO_{2max} in large population of healthy young men and women. Balke (107) developed a field performance test using a 15-min run to assess the aerobic fitness of military personnel. Cooper (23) later shortened the test to 12 min and introduced the 1.5-min run as an alternative to the 12-min run. Correlations between predicted and measured VO_{2max} for the field tests ranged from r = 0.53 to r = 0.90. A high correlation between the laboratory-determined VO_{2max} and the distance run was first reported by Balke (15-minute run) (83). No pattern in predictive accuracy could be identified when comparing tests of different distances (61). Some of the tests, such as the Cooper 12-minute run, are still commonly used today but this test fails to account for age or body weight, which can influence exercise responses (71). Many of the protocols listed Table 4 were developed using only one gender (23, 24, 25, 32, 33, 35). Of the remaining tests, only those developed by Dolgener et al. (30), Kline et al. (28), and Oja et al. (36) used subjects with a wide age range. The range of VO_{2max} values was not reported for most studies. Therefore, a comparison of subject aerobic capacities is not possible.

In addition, the 1-Mile Track Walk Test (1-MTW), also known as the Rockport Fitness Walking Test (RFWT), estimates VO_{2max} across a broader range of adult population and fitness levels. Kline et al (28) originally validated the RFWT on adults, 183 men and 207 women between 30 and 69 years of age. O'Hanley et al. (72) found the one mile walking test to

Table 4. Test protocols developed for estimating VO_{2max} using field walking and running.

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
Balke, 1963 (107)	8	22-50	M	46.1	12-min run time	---	---	---
Falls, 1965 (25)	87	23-58	M	39.50 ± 7.60	50-yd dash, shuttle run, 600 yd run, and pull-ups	0.724	0.524*	4.72
Doolittle & Bigbee, 1968 (24)	9	14-15	M	---	600 yard run time	---	0.810	---
Cooper, 1968 (23)	115	17-52	M	31-59	12-min walk/run distance	---	0.805	---
Ribisl et al, 1969 (111)	24 11	34-48 19-22	M M	48.55 ± 5.84 57.35 ± 3.68	2 mile run time, age, and wt 2mile run time, 100 yard dash time and 440 yard dash time	0.95 0.94	---	1.97 1.55
Maksud et al, 1971 (110)	17	11-14	M	47.4 ± 4.0	12-min run time	0.65	---	---
Burkle, 1976 (108)	44	17-30	M	52.79 ± 6.09	12-min run time	0.90	0.81	2.65
Gutin et al, 1976 (109)	20	10-12	M/F	47.5 ± 5.8	12-min run time	0.75	---	---
Getchell et al, 1977 (32)	21	18-25	M	35.0 ± 55.4	1.5 mile run time	---	0.837	---
Myles et al, 1980 (35)	32	23.2 ± 3.9	M	48.0 ± 5.1	2.4 km run time 4.8 km run time	---	0.774 0.689	---
Kline et al, 1987 (28)	343	30-69	M F	37.0 ± 10.7	1-mile walk time, age, HR, and wt	---	0.93	0.325+
O'Hanley at al 1987 (72)	19	70-79	F	30.4 ± 4.3	1.5 mile run time	0.84	---	2.8
Jackson et al, 1990 (33)	50	21.7	M	54.23 ± 7.08	3-mile run time	---	0.58	5.77
MacNaughton et al, 1990 (27)	142 142	12-15 12-15	M/F M/F	---	5 min run distance 15 min run distance	---	0.285-0.564 0.450-0.776	---
Oja et al, 1991 (36)	34 28	20-65 20-65	M F	48.0 ± 5.1 48.0 ± 5.1	2 km walk time, age, HR, and BMI	0.84 0.83	0.75 0.73	3.3 5.1
Fenstermaker et al, 1992 (31)	82	69.4 ± 4.2	F	21.05 ± 3.30	1-mile walk time, age, gender, HR, and wt	---	0.624	2.02
George et al, 1993 (10)	54	21.4 ± 2.7	M/F	46.6 ± 6.1	1 mile jog time, gender, wt, and HR	0.87	0.751*	3.0
"	49	22.5 ± 3.0	M/F	48.1 ± 6.4	1.5 mile time, gender, HR, and wt	0.90	0.810*	2.8

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; SEE: standard error of estimate; BMI: body mass index; "+"; liter·min^{-1}.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

Table 4. (concluded)

Investigators	N	Age	Gender	VO_{2max}	Variables	r	R^2	SEE
Dolgener, 1994 (30)	196	19.4 ± 2.74	M/F	2.82 ± 0.75+	1-mile walk time, age, gender, HR and wt	0.84	0.706	0.397+
Cureton et al, 1995 (29)	490 263	8-25	M F	50.10 ± 4.70 45.0 ± 3.6	1 mile walk/run time, age, gender, and wt	0.71 0.41	0.462	5.0 4.5
George et al, 1998 (26)	85	18-29	M/F	42.80 ± 6.60	1 mile jog time, gender, age, wt, and HR	0.85	---	3.48
Larsen et al, 2002 (34)	101	20.5 ± 2.4	M/F	46.0 ± 6.0	1.5 mile walk/run time, HR, gender, and wt	0.90	0.810*	2.87

Note: R: multiple regression coefficient; wt: weight; ht: height; HR: heart rate; SEE: standard error of estimate; BMI: body mass index; "+"; liter·min^{-1}.
*adapted from Ebbeling et al, (1988). Development of a single-stage submaximal treadmill walking test.

accurately predict VO_{2max} for males between 70 and 79, but it significantly underestimated VO_{2max} for females between 70 and 79. Fenstermaker et al. (31) also researched the use of RFWT on an older population. The walking test was found to provide valid estimates for females ≥ 65 years of age. Coleman et al. (73) evaluated the use of the RFWT on adults between 20 and 29 years. The equations were found to accurately estimate $VO_{2max.}$ However, Dolgenner et al. (30) found the RFWT to systematically overestimate VO_{2max} when used on college-aged individuals. In agreement with Dolgener et al. (1994), George et al. (26) also found the RFWT to overestimate VO_{2max}. This test is applicable to a wide range of individuals. It requires little specialized equipment and uses the familiar activity of fast walking. In addition, no research was found in the literature pertaining to validity of the RFWT using less than maximal walking speed.

Regression Prediction Approach

Many multi-staged treadmill tests for predicting an individual's VO_{2max} have been explored but few of these have sufficient data regarding their validity and reliability using the regression prediction approach. ACSM's Guidelines for Exercise Testing and Prescription 7th ed. states that the basic aim of submaximal exercise testing is to determine the heart rate response to one or more submaximal work rates and use the results to predict VO_{2max} (Figure 1). McArdle, Katch, and Katch (43) also state the same concept in the exercise physiology book. A heart rate obtained from at least two submaximal exercise intensities may be extrapolated up to the age-predicted maximal heart rate and a vertical line may be drawn from that point downward to calculate a predicted VO_{2max} (Figure 2).

A few assumptions regarding testing are needed to ensure the highest degree of accuracy when using submaximal exercise testing to estimate VO_{2max}: 1) Selected workloads must be reproducible; 2) A steady-state heart rate is obtained during each stage of the test. (Usually, workload durations of 2 minutes or more are used to ensure steady state); 3) The maximal heart rate for a given age is accurately predicted by the formula (HR = 220 - age); 4) Heart rate and VO_2 have a linear relation over a wide range of values (thus, the slope of HR/VO_2 regression can be extrapolated to an assumed maximum heart rate); 5) Mechanical efficiency (i.e., VO_2 at a given work rate) is consistent (74).

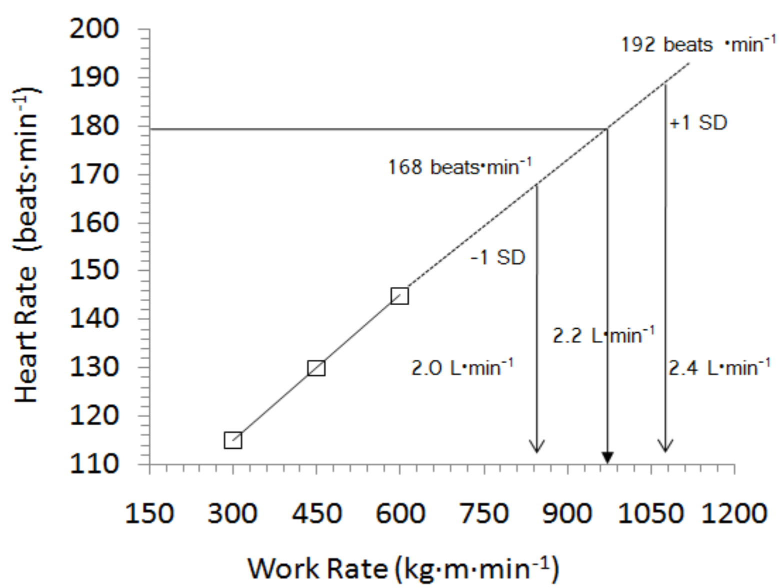


Figure 1. ACSM's Guidelines regression prediction approach.
-Source from ACSM's Guidelines for Exercise Testing and Prescription 7th ed. (page. 75)

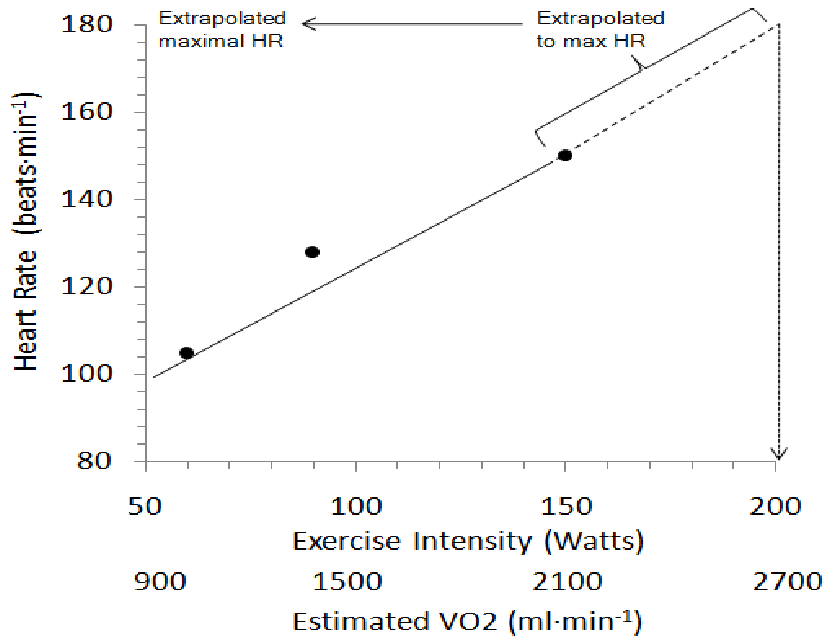


Figure 2. Extrapolating the linear relationship between submaximal HR and oxygen consumption up to VO_{2max}

-Source from McArdle WO, Katch FI, Katch VL. Exercise Physiology, Nutrition, and Human performance. Phildelphia: Lee & Febiger, 5th ed. (page. 242)

CHAPTER III
METHODS

The All data collection was performed in the Applied Physiology Laboratory (Health, Physical Education, and Recreation building) on the campus of the University of Tennessee, Knoxville.

Participants

32 males and 16 females (N = 48), 18 to 59 years of age, volunteered to participate in the study. Participants were eligible for this study only if they had no apparent contraindications to exercise tests. Prior to participating in the study, each participant completed a health history questionnaire (Appendix B) and signed a consent form (Appendix A) approved by the University of Tennessee-Knoxville Institutional Review Board. Each participant completed two separate exercise treadmill tests, including one submaximal test and one maximal test. Each test was performed on a separate day.

Submaximal exercise testing

On the first day of testing each subject's weight was measured using a physician's scale. Height was measured using a stadiometer. A sub-maximal exercise test was then performed on a motorized treadmill (Quinton Q65, Seattle, WA) using the Bruce protocol (42). The test was performed at various times of day; however, subjects were asked to abstain from exercise for four hours before the test. During the sub-maximal exercise test, the subject was fitted with a reusable cardiorespiratory fitness mask connected to a 28 mm optoelectronic reader (Rome, Italy), as well as a Polar (Kempele, Finland) heart rate transmitter. The cables from the optoelectronic reader and Polar heart rate receiver were then connected to the rear panel of the Fitmate. The Fitmate was calibrated by Cosmed (Rome, Italy) at the factory and prior to each test this system underwent an auto-calibration. VO_2 and heart rate were obtained on 15 second intervals. The speed of the treadmill was set at 1.7 mph and was subsequently increased to 2.5 mph, 3.4 mph, 4.2 mph, 5.0 mph and 5.5 mph at 3-minute intervals throughout the test. The treadmill incline started at a 10% grade and was increased by 2% every three minutes until subjects reached 85% of age-predicted maximal heart rate (220 - age) at which time the test was stopped. The VO_{2max} for the Fitmate is estimated by extrapolating the linear regression relating heart rate and measured oxygen consumption to the age-predicted maximal heart rate (220 – age). For the ACSM metabolic equations, submaximal VO_2 is computed as: (VO_2 $ml \cdot kg^{-1} \cdot min^{-1}$= $[(m \cdot min^{-1}) \times 0.1] + [(m \cdot min^{-1}) \times 1.8 \times \text{grade (decimal)}] + 3.5$) at stage 1, 2, 3 with HR obtained at the end of last 30 second average for each stage. Then VO_{2max} is estimated by drawing a best-fit straight line through three data points that relate HR and predicted VO_2. This line is extrapolated to the age-predicted maximal heart rate and VO_{2max} is then predicted by drawing a vertical line to the oxygen consumption.

Maximal exercise testing

On the second day of testing each subject performed a maximal treadmill exercise test using the Bruce protocol (42). Subjects were equipped with a noseclip and a mouthpiece used for data collection. A Hans Rudolf 2700 series two-way, non-rebreathing valve (Kansas City, MO) was attached to the mouthpiece and tube. A tube was connected to a three-way 2100 series Hans Rudolf stop-cock. A three-way 2100 series Hans Rudolf stop-cock and Douglas bag were attached to the Hans Rudolf 2700 series two-way, non-rebreathing valve to collect expired gases.

Expired gases were collected in 300 grams meteorogical ballons (Huntington Station, NY) and analyzed to calculate ventilation, oxygen consumption, and carbon dioxide production using a ParvoMedics TrueMax 2400 (Sandy, UT) metabolic cart. The Hans-Rudolph (Kansas

City, MO) pneumotachometer was calibrated before each use with a 3.00 L syringe, and the gas analyzers were calibrated against concentration of known gases previously analyzed using the Scholander technique. The subject was instructed to use appropriate hand gestures to signal volitional exhaustion, or to terminate the test for any other reason. In addition, the subject was verbally encouraged to exercise to volitional exhaustion. During exercise testing, the subject also wore the Polar 610i (Kempele, Finland) heart rate chest strap and wristwatch. The heart rate watch was set to record heart rate at 5 second intervals. Once the subject's HR reached 88% of age-predicted maximal heart rate, the expired gases were collected in a Douglas bags every 30 seconds until the test was ended. Douglas bag collections of expired gases (fraction of O_2 and CO_2) were determined by the TrueMax 2400 metabolic cart and the expired volume was then measured by pushing the collected gas through a 120-liter Tissot gasometer (Warren E. Collins, Braintree, MA).

Statistical Analysis

Mean and standard deviations were calculated for age, height, weight and BMI. Repeated measures ANOVA was used to compare the predicted and measured values of VO_{2max}. Simple linear regression analysis was used to determine the relationship between the VO_{2max} from the maximal treadmill test and the predicted VO_{2max} from the submaximal treadmill test. Using this analysis, standard error of estimate (SEE) was analyzed. A paired sample t-test was done to determine difference between predicted maximal HR (beats·min^{-1}) and measured maximal HR (beats·min^{-1}). For all statistical comparisons, the level of significance was set at $P <0 .05$ and all values are reported as means ± standard deviation. All statistics were using SPSS 15.0.

CHAPTER IV
RESULTS

The primary purpose of this study was to assess the validity of the Cosmed Fitmate (FM) in predicting maximal oxygen consumption (VO_{2max}), compared to the Douglas bag (DB) method. In addition, this study examined whether measuring submaximal VO_2, rather than predicting it, can improve upon the prediction of VO_{2max}. All subjects (32 males and 16 females) completed both trials. No exercise tests were stopped due to test termination criteria outlined by the ACSM (5).

Physical Characteristics

The physical characteristics of the subjects are presented in Table 5. The average ages of the male and female subjects were 29.4 ± 9.7 and 33.0 ± 10.2 years old (mean ± SD), respectively. They had a body mass of 80.5 ± 9.7 and 57.5 ± 5.3 kilograms and a BMI of 24.6 ± 3.0 and 21.0 ± 1.9 kg·m^{-2}, respectively.

Table 5. Physical characteristics of male (n = 32) and female (n = 16) subjects

Measurement	Male (mean ± SD) N = 32	Range	Female (mean ± SD) N = 16	Range
Age (yr)	29.4 ± 9.7	19.0 – 59.0	33.0 ± 10.2	20.0 – 51.0
Weight (kg)	80.5 ± 9.7	69.3 – 106.8	57.5 ± 5.3	46.0 – 65.5
Height (cm)	180.8 ± 6.2	168.5 – 197.0	165.5 ± 5.3	157.9 – 174.0
BMI (kg·m^{-2})	24.6 ± 3.0	19.3 - 34.3	21.0 ± 1.9	17.1 - 24.7

Characteristics of VO_{2max}

The data from the measured and predicted VO_{2max} (ml·kg^{-1}·min^{-1}), HR (bpm), and RER values are listed in Table 6. VO_{2max} was defined by a respiratory exchange ratio (RER) greater than 1.1, or maximum HR within 11 beats·min^{-1}. All subjects tested satisfied 1 or more of these criteria. Mean values (± SD) : a) measured VO_{2max} with Douglas bag was 46.5 ± 8.8 ml·kg^{-1}·min^{-1}, b) predicted VO_{2max} using the Fitmate with the predicted heart rate (220 - age) was 45.6 ± 8.8 ml·kg^{-1}·min^{-1}, c) predicted VO_{2max} using the measured maximal HR with the Fitmate was 44.5 ± 7.8 ml·kg^{-1}·min^{-1}, and d) predicted VO_{2max} using ACSM regression prediction equation was 51.1 ± 7.9 ml·kg^{-1}·min^{-1}. Repeated measures ANOVA revealed that overall there was a significant difference ($p = 0.00$) between measuremnts, but there was no significant difference between VO_{2max} predicted with the Fitmate and VO_{2max} measured with Douglas bag method ($p = 0.152$). In contrast, there was a significant difference ($p = 0.01$) between VO_{2max} predicted from the ACSM prediction regression equation and VO_{2max} measured by the Douglas bag method. In addition, there was also significant difference between VO_{2max} predicted with measured maximal HR and VO_{2max} measured by the Douglas bag method ($p = 0.01$). A paired t-test indicated that there was no significant difference ($p = 0.091$) between predicted maximal HR (HR = 220-age) and measured maximal HR.

Correlations

A correlation matrix was produced and is presented in Table 7. Correlations were calculated to assess the relationship between measured VO_{2max} values with the Douglas bag method and; a) predicted VO_{2max} using the Fitmate with age-predicted maximal heart rate (220 – age), b) predicted VO_{2max} using the Fitmate with measured maximal HR, and c) predicted

VO_{2max} with ACSM regression prediction equation. The significant correlations are presented as scatter and Bland-Altman plot charts in Figures 3 - 5.

Measured VO_{2max} and predicted VO_{2max} using the Fitmate with the age-predicted maximal heart rate (220 – age) were significantly, positively correlated, $R = 0.804$ ($p < .01$) with standard error of estimate (SEE = 3.97 $ml \cdot kg^{-1} \cdot min^{-1}$) and is displayed in Figure 3. Positive and significant correlation also existed between measured VO_{2max} and predicted VO_{2max} using the measured heart rate with the Fitmate, $R = 0.797$ ($p < 0.01$) with standard error of the estimate (SEE = 3.57 $ml \cdot kg^{-1} \cdot min^{-1}$) shown in Figure 4. Predicted VO_{2max} using ACSM regression prediction equation with measured $VO_{2max,}$ $R = 0.574$ ($p < 0.01$) with standard error of estimate (SEE = 5.26 $ml \cdot kg^{-1} \cdot min^{-1}$), shown in Figure 5. Lastly, Figure 6 shows the relationship between predicted maximal HR ($beats \cdot min^{-1}$) using ACSM age-prediction equation (220 – age) and measured maximal HR ($beats \cdot min^{-1}$) with maximal exercise testing, $R = 0.35$ ($P < 0.01$) with standard error of estimate (SEE = 8.20 $beats \cdot min^{-1}$).

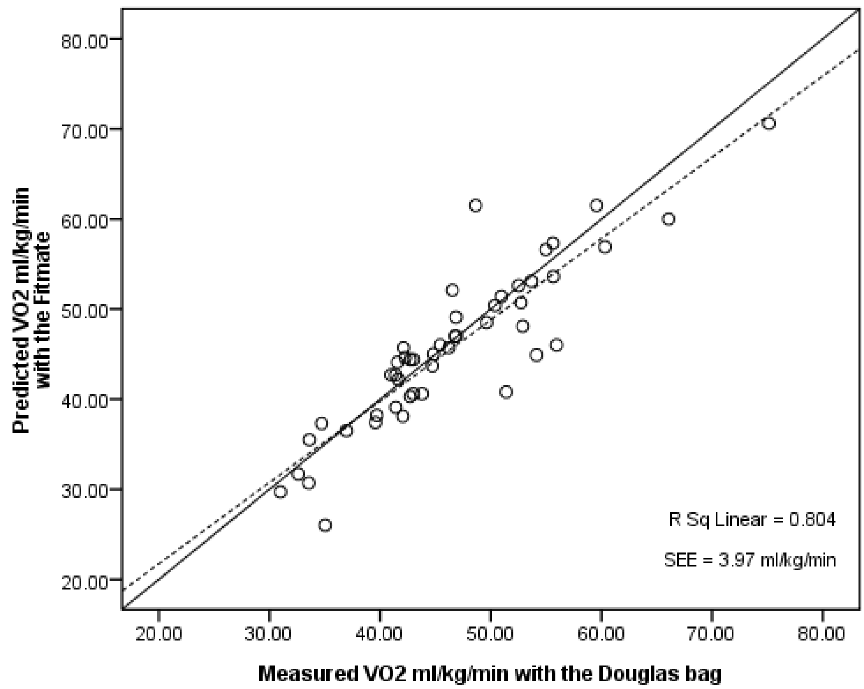
Table 6. Measured and predicted relative VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) values

Treatment	N	Mean ± SD	Range
VO_2 with Douglas Bag ($ml \cdot kg^{-1} \cdot min^{-1}$)	48	46.52 ± 8.83	30.9 – 75.1
VO_2 with Fitmate: predicted HR max ($ml \cdot kg^{-1} \cdot min^{-1}$)	48	45.67 ± 8.89	26.0 – 70.6
VO_2 with Fitmate : measured HR max ($ml \cdot kg^{-1} \cdot min^{-1}$)	48	44.56 ± 7.88	30.0 – 68.0
VO_2 with ACSM prediction equation ($ml \cdot kg^{-1} \cdot min^{-1}$)	48	51.16 ± 7.98	33.0 – 78.4
Measured Heart Rate (bpm)	48	186 ± 8.8	166 – 214
Predicted Heart Rate (bpm)	48	189 ± 10.6	160 – 201
RER	48	1.23 ± 0.01	1.14 – 1.47

Table 7. Correlation matrix and standard error of estimate

Treatment	Douglas bag	Fitmate	Fitmate with measured Max HR	ACSM prediction equation
Douglas Bag (Criteria) (n = 48)	1	0.897** SEE = 3.97	0.894** SEE = 3.57	0.758** SEE = 5.26
Fitmate (n = 48)		1	0.908** SEE = 3.34	0.771** SEE = 5.14
Fitmate with measured HR Max (n = 48)			1	0.776** SEE = 5.09
ACSM prediction equation (n = 48)				1

** Correlation is significant at the 0.01 level (2-tailed).
SEE is a standard error of estimate value (ml·kg^{-1}·min^{-1})



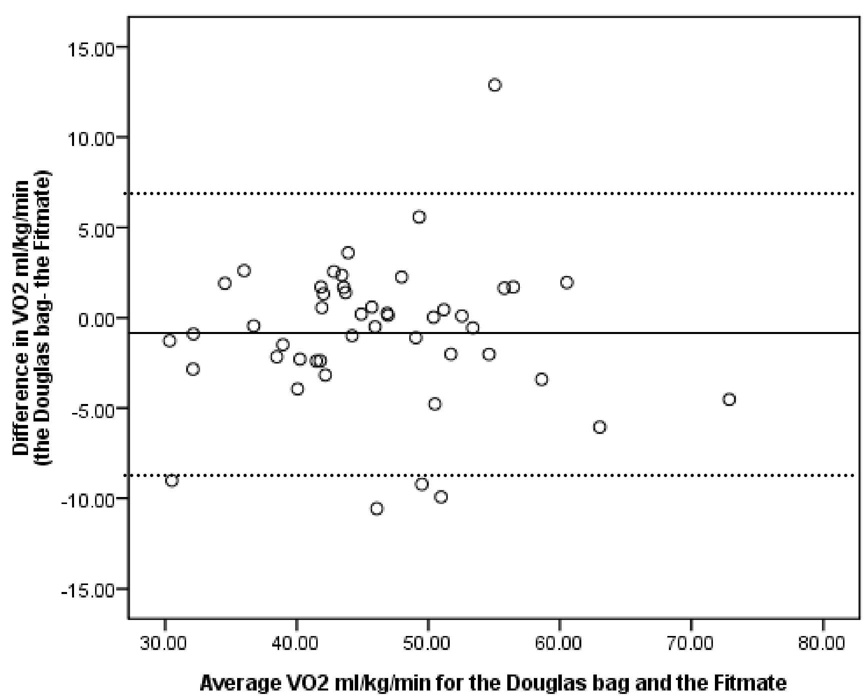
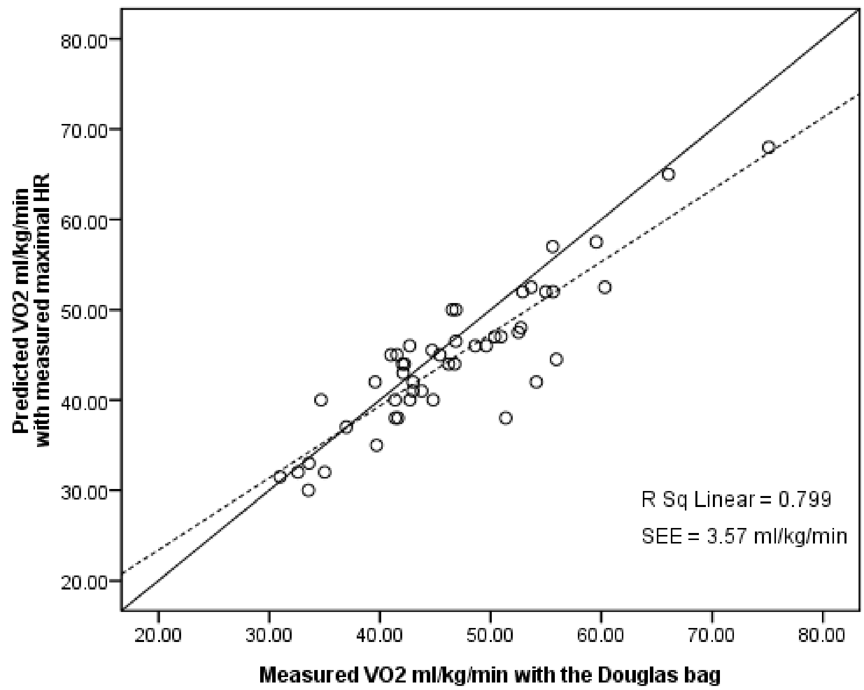


Figure 3 - The top figure shows relationship between predicted (Fitmate) vs. measured (Douglas bag) maximal oxygen consumption ($R = 0.804$. $p < 0.01$; SEE = 3.97 $ml \cdot kg^{-1} \cdot min^{-1}$). The bottom figure is the respective Bland-Altman plot showing individual error scores.



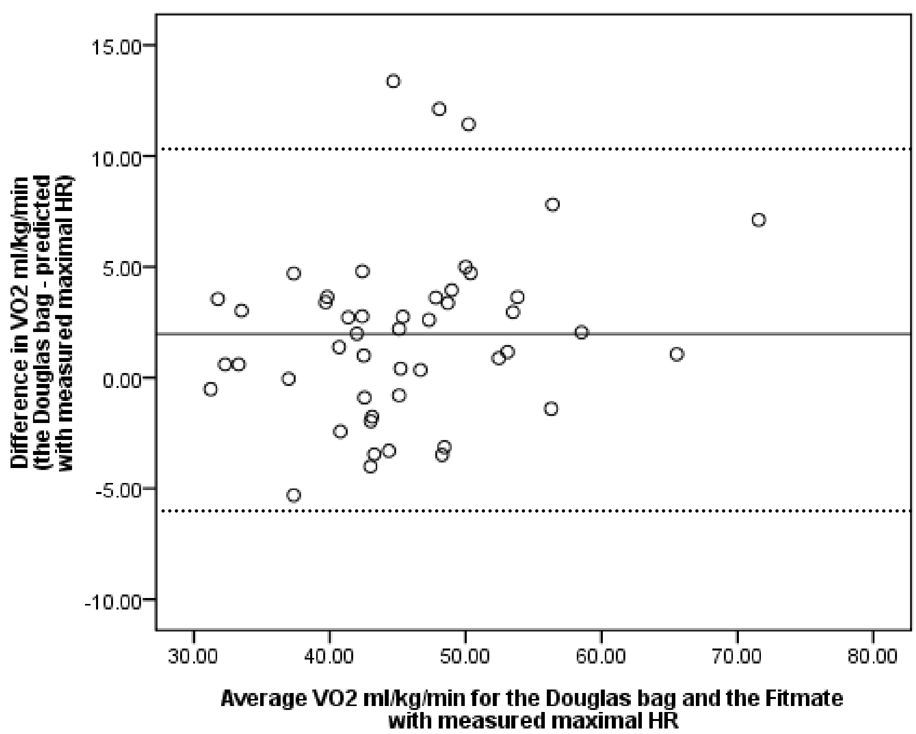


Figure 4 - The top figure shows relationship between predicted (Fitmate) with measured max HR vs. measured (Douglas bag) maximal oxygen consumption ($R = 0.799$. $p < 0.01$; SEE = 3.57 $ml \cdot kg^{-1} \cdot min^{-1}$). The bottom figure is the respective Bland-Altman plot showing individual error scores.

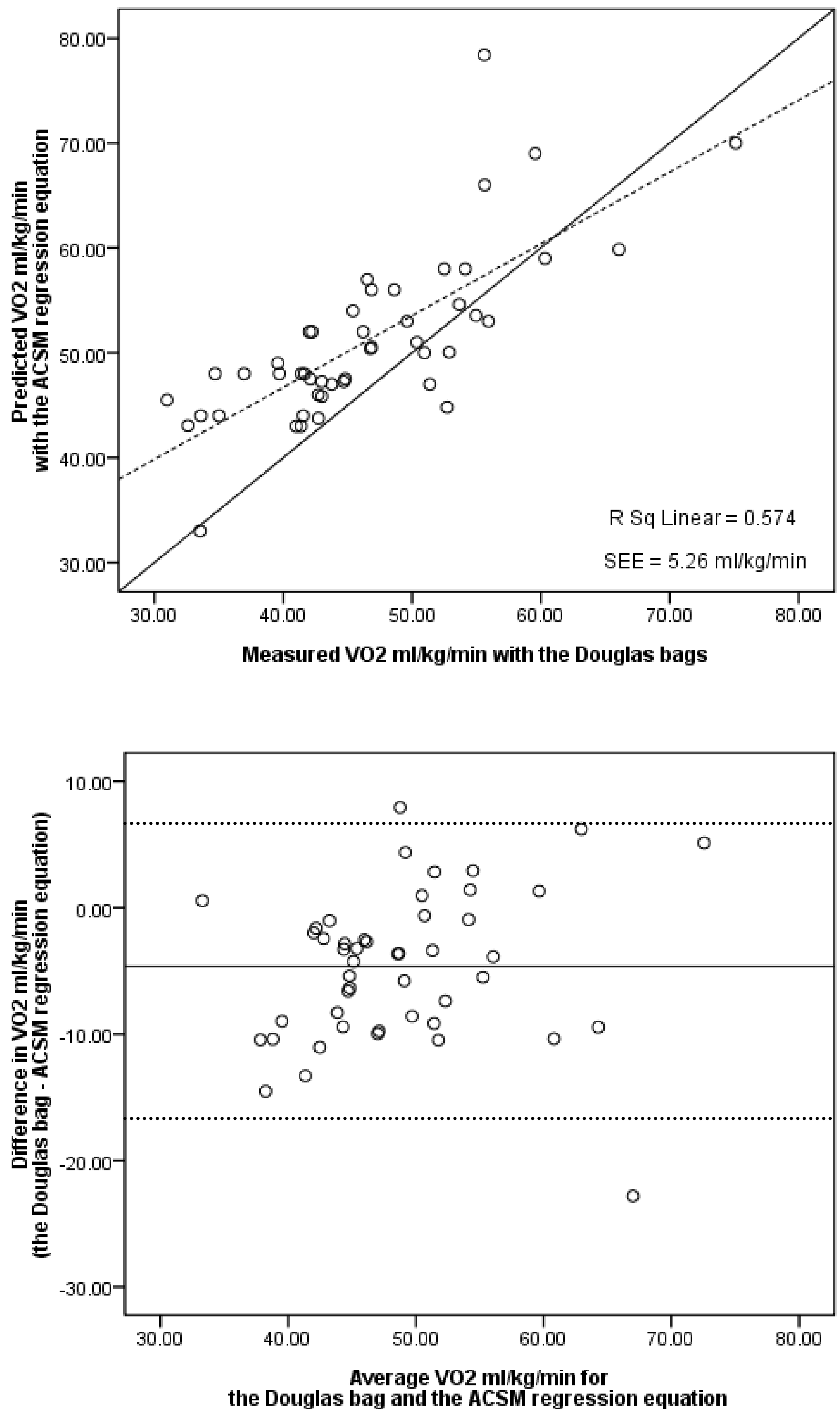
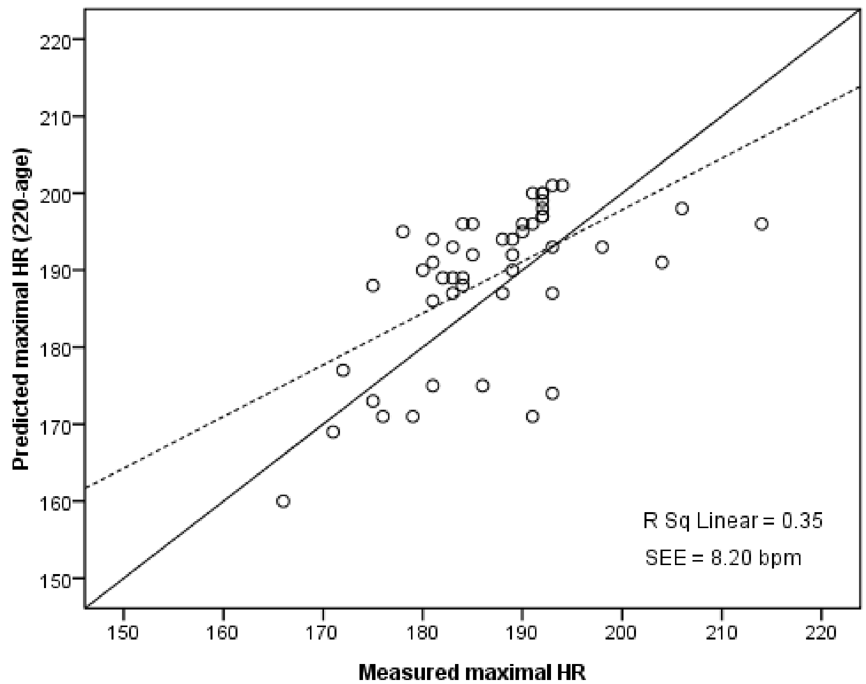


Figure 5 - The top figure shows relationship between predicted with ACSM regression equation vs. measured (Douglas bag) maximal oxygen consumption ($R = 0.574$. $p < 0.01$; $SEE = 5.26$ $ml \cdot kg^{-1} \cdot min^{-1}$). The bottom figure is the respective Bland-Altman plot showing individual error scores.



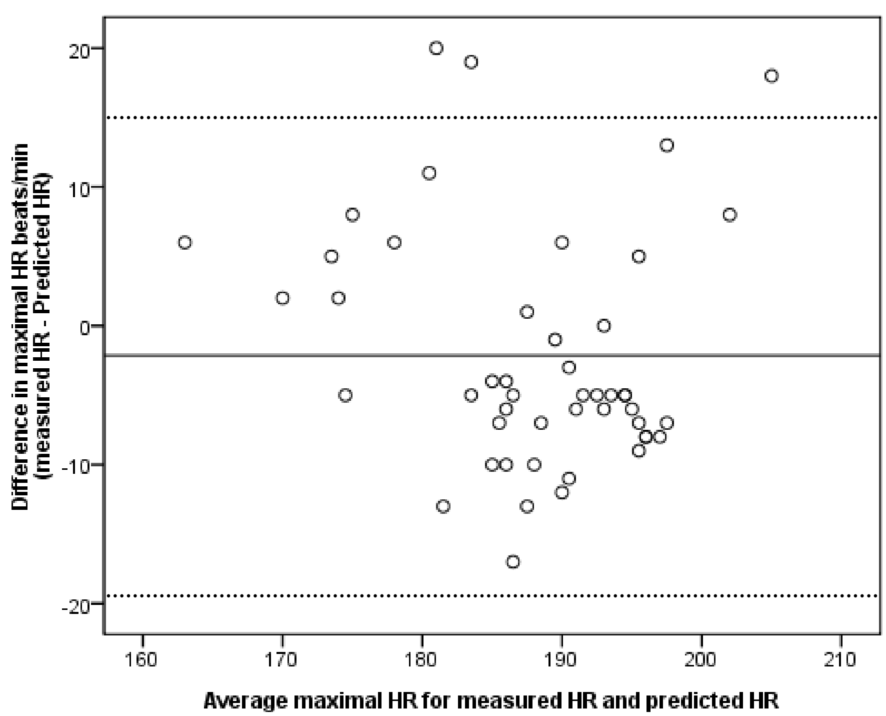


Figure 6 - The top figure shows relationship between predicted (220 – age) vs. measured max HR (R = 0.35. $p < 0.01$; SEE = 8.20 beats·min^{-1}). The bottom figure is the respective Bland-Altman plot showing individual error scores.

CHAPTER V
DISCUSSION AND CONCLUSIONS

The primary aim of this investigation was to test the validity of the Cosmed Fitmate in predicting VO_{2max} compared to the Douglas bag method. A secondary aim was to attempt to determine whether measuring submaximal VO_2, rather than predicting it, can improve upon the prediction of VO_{2max}.

The present study found that the use of a simple submaximal treadmill test with the Fitmate metabolic system provides better prediction of VO_{2max} than the ACSM regression prediction equation. The reduction in error when predicting VO_{2max} using the Fitmate may be due to the accuracy of measuring VO_2 at each submaximal work rate, rather than predicting it. Instead of assuming an average VO_2 (as predicted by the ACSM walking equations), it measures the V_E and F_EO_2 to arrive at an accurate measure of the oxygen cost. This eliminates one source of error. However, the Fimate test using the Bruce protocol is still not entirely accurate. To some extent, this is due to the inherent inaccuracy in predicting maximal HR. If one uses the measured maximal HR, this slightly improves the prediction of VO_{2max}. This shows that the errors in predicted maximal HR contribute to the error in predicted VO_{2max}. The traditional equation underestimates maximal HR in older populations and tends to overestimate maximal HR in young individuals (76).

When measuring VO_{2max} and maximal HR values with the Bruce protocol, there are no individualized testing procedures for participants with varying fitness levels or age, yet all are required to perform a standard graded exercise test (GXT) until they achieve volitional exhaustion (77). As such, certain participants may be required to exercise at a grade or treadmill speed that is not suited to their functional ability. Additionally, to be time efficient the Bruce protocol imposes relatively large, abrupt increases in exercise intensity between stages that may excessively challenge participants (especially as they approach maximal exertion) and consequently, this may cause certain participants to stop the test before they achieve maximal VO_{2max} and HR (62).

There is another possible limitation in predicting VO_{2max} due to initial work rate (speed) of the Bruce protocol during the submaximal exercise test. Research comparing walking and running protocols indicates that the highest oxygen consumption values are obtained from running tests. Sheehan (120) compared four methods of determining VO_{2max}. The four protocols used were continuous walking, continuous running, intermittent running, and continuous running while holding the handrail. Oxygen consumption measured by the three running tests showed significantly ($p < 0.05$) higher absolute and relative VO_{2max} values than the walking test. In addition, Stamford (119) investigated the oxygen consumption responses of three groups of adults to different walking and running protocols. Walking values for $VO_{2\ max}$ were significantly ($p < 0.05$) lower than those from the running protocols for all groups. In other words, the Fitmate's prediction of VO_{2max} can be affected by the Bruce protocol, where the initial stages consist of walking at 1.7 mph, 2.5 mph, 3.4 mph, and sometimes at 4.2 mph. Therefore, the measured VO_2 and HR might be lower at the beginning of three stages than running protocol. It is suggested that the choice of exercise modality during the submaximal exercise with the Fitmate may impact the predicted VO_{2max}.

In comparison to other submaximal treadmill tests (Table 3) used to predict VO_{2max}, the present study has comparable accuracy for estimating VO_{2max} without the use of highly trained personnel, expensive equipment or complicated regression equations for interpreting results. Metz and Alexander (8) report an r of 0.701 with SEE of 3.12 $ml \cdot kg^{-1} \cdot min^{-1}$ for their submaximal treadmill test. A limitation of their protocol is that direct measurement of expired gases is needed to predict VO_{2max}, a major drawback to estimating VO_{2max} in many applied or non-laboratory settings (38). Another limitation of this study is that the subject population studied was 12-13 year old boys.

Similar to the current study, Montoye et al. (40) in 1986 examined the prediction of VO_{2max} using the linear relationship between HR and VO_2. Montoye et al. (40) reported a correlation coefficient of 0.72 and an SEE of 3.7 $ml \cdot kg^{-1} \cdot min^{-1}$. They concluded that submaximal tests were probably useful only when following the same subject over time or in comparing mean VO_{2max} for various age groups. In addition, George et al. (20) report an r of 0.84 with an SEE of 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$ for their submaximal jogging treadmill test. However, a limitation of this study was conducted on a homogeneous sample of college aged individuals and age was not found to be an important variable in the estimation of VO_{2max}. For this reason, discretion should be used when applying the results of this study to individuals who are older or younger than 18-29 year old.

In conclusion, the present study evaluated the validity of a commercially available device (Cosmed Fitmate) that uses a simplified procedure for conducting Bruce submaximal GXTs. The study shows that Fitmate is a small, portable, and easy-to-use metabolic system that provides reasonably good estimates of VO_{2max}. Furthermore, measuring submaximal VO_2, rather than predicting it from the ACSM metabolic equations, improves the prediction of VO_{2max}. In general, it appears that submaximal tests are accurate enough for the purpose of classifying an individual’s fitness level according to standard values (48). Submaximal testing is valuable for determining VO_{2max} situations where the necessary equipment to perform maximal testing is unavailable. Reasonable estimates of VO_{2max} provide fitness and health practitioners with important information to make decisions regarding exercise recommendations and health management for the apparently healthy individual.

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APPENDICES

Appendix A
(Informed Consent)

INFORMED CONSENT FORM

Validation of the Cosmed Fitmate in Predicting Maximal Oxygen Consumption (VO_{2max})

INVESTIGATOR: Jungmin Lee

ADDRESS:
The University of Tennessee
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322 HPER
1914 Andy Holt Ave.
Knoxville, TN 37966

TELEPHONE: (865) 974-5091

FACULTY ADVISOR: Dr. David R. Bassett

ADDRESS:
The University of Tennessee
Department of Health and Exercise Science
343 HPER
1914 Andy Holt Ave.
Knoxville, TN 37966

TELEPHONE: (865) 974-8766

PURPOSE

You are invited to participate in a research study. The purpose of the study is to assess the validity of the Cosmed Fitmate™ in predicting maximal oxygen consumption. If you give your consent, you will be asked to perform the two separate tests stated below. Each test will take no more than one hour to complete. You will first be asked to complete a health questionnaire to determine your health status prior to participation. On your first visit, Height, weight, sub-maximal with Cosmed Fitmate™ will be measured and on your second visit, maximal oxygen consumption with the Douglas bag will be measured in the Applied Exercise Physiology Laboratory in the Health, Physical Education, and Recreation (HPER) building on the University of Tennessee, Knoxville campus.

TESTING

1. Height and weight will be measured.
2. Heart rate will be monitored during each trial using a heart rate monitor. An electrode will be strapped around your chest and you will wear a watch that will read and record your heart rate.
3. A sub-maximal exercise test will be performed on a motorized treadmill. The test can be done at any time of the day; however, you are asked to abstain from exercise for four hours before the test. A treadmill graded exercise test with the Bruce protocol will be used. The speed of the treadmill will be subsequently increased at 1.7 mph, 2.5 mph, 3.4 mph, 4.2 mph, 5.0 mph and 5.5 mph every three minutes throughout the test. The incline of the treadmill will start at 10% grade and will be increased by 2% every three minutes until you reach 85 % of age-predicted maximal heart rate at which time we will stop the test. During the exercise test you will breathe through a facemask.
4. Maximal Oxygen uptake (VO_{2max}), which is the maximum amount of oxygen your body can take in and use per minute. For this test a machine will be used to measure the amount of oxygen and carbon dioxide you exhale during exercise. You will breathe through a mouthpiece while wearing a nose clip to prevent nasal breathing. You will walk or run on a motorized treadmill at a starting speed of 1.7 mph. The speed of treadmill will be subsequently increased to 2.5 mph, 3.4 mph, 4.2 mph, 5.0 mph and 5.5 mph every three minutes throughout the test. The incline of the treadmill will start at 10% grade and will be increased by 2% every three minutes. You will run until you feel you are unable to continue, at which time we will stop the test.

POTENTIAL RISK OF PARTICIPATION

The exercise tests used in this study may cause some muscle soreness because of their intensity but it should dissipate within a few days. Although exercise testing generally is considered a safe procedure, both acute myocardial infarction and cardiac arrest have been reported and can be expected to occur at a combined rate of up to 1 incident per 2,500 tests.

BENEFITS OF PARTICIPATION

You will be provided with a report listing your maximal oxygen uptake (VO_{2max}), which is a measure of cardiovascular fitness. This information may be helpful in planning modification to your training fitness program.

CONFIDENTIALITY

Only Jungmin Lee and Dr. Bassett will have access to your data. All data will be coded by subject number rather than name and will be kept in a locked file cabinet in room 317 of the HPER Building. The result of the study will be published, but your name will not be associated with any of the material published.

RIGHT TO ASK QUESTIONS AND/OR WITHDRAW FROM THIS STUDY

If you have questions at any time concerning the study or procedures, you may contact either Dr. Bassett at (865) 974-8766 or Jungmin Lee at (865) 974-5091. If you have questions about your rights as a research participant, please contact the Research Compliance Services at (865) 974-3466. You are free to decide whether or not to participate in this study and free to withdraw from the study at any time.

AUTHORIZATION

By signing this informed consent form, I am indicating that I have read and understood this document and have received a copy of it for my personal records. I have been given the opportunity to ask questions on any matters that I am not clear on. By signing this form I indicate that I agree to serve as a participant in this research study.

____________________________ _______________________

Participant’s signature Date

____________________________ _______________________

Investigator’s signature Date

Appendix B
(Health History Questionnaire)

(Staff Use) ID# ____________

HEALTH HISTORY QUESTIONNAIRE

(Staff Use) DATE ____________

Name: ____

Address: ____

City: ______________________________ **Zip Code:** ____________

Phone: ____________________ **Date of Birth:** ________________ **Age:** ____________

Gender: ___ M ___F **UT Faculty/Staff:** __Y _____N **Do You Live Alone?** ________ Y ________ N

Occupation: ______________________ **Full Time?** _______ Y _______ N

Marital Status: (circle one) Single Married Divorced Widowed

Education: (check highest level completed)

Elementary ________ High School ________ College ________ Graduate School________

Race: White ________ American Indian ________ Asian ________ Hispanic ________

Black / African American ____________ Native Hawaiian / Pacific Islander __________ Other ___________

Personal Physician: ______________________ **Location:** ________________

Are you taking any prescription or over-the counter medication? YES __________ NO ________

Name of Medication Reason for Taking For How Long?

____

____

____

____

____

____

Please Turn Over

Emergency Contact

Name: ____

Relationship: ____________ Phone: Work: ____________________

Home: ____________________

PAST HISTORY
Have you ever had? (please check all that apply)
_____Heart attack
_____ Stroke
_____ Any heart problems
_____ Blood Clots
_____ Arthritis
_____Cancer
_____ Recurring leg pain (not related to arthritis)
_____ Liver or Kidney Disease
_____ Any breathing or lung problems
Ankle swelling (not related to twisting)

PRESENT SYMPTOMS

Do you currently have? (please check all that apply)

_____ Chest pain / discomfort	_____ Cough on exertion
_____ Shortness of breath	_____ Coughing of blood
_____ Heart palpitations	_____ Dizzy spells
_____ Skipped heart beats	_____ Frequent headaches
_____ Chronic Fatigue Syndrome	_____ Orthopedic / joint problems
Diabetes	Back Pain

Appendix C
(Raw Data)

Subject	Age	Gender	Height	Weight	BMI	RER	Predicted Max HR	Measured Max HR	Predicted VO_{2max} with ACSM	Predicted VO_2 max with Measured max HR	Predicted VO_{2max} with Fitmate	Measured VO_{2max}
1	28	1	188.0	83.9	23.7	1.19	192	189	54.60	52.50	53.10	53.66
2	24	1	172.3	69.3	23.3	1.25	196	185	69.00	57.50	61.50	59.55
3	27	1	185.0	75.0	21.9	1.29	193	183	50.40	44.00	47.00	46.75
4	50	1	181.0	76.4	23.3	1.14	171	179	50.50	50.00	47.00	46.87
5	24	1	191.0	72.5	19.9	1.21	196	191	70.00	68.00	70.60	75.12
6	23	1	197.0	75.0	19.3	1.28	197	192	44.80	48.00	50.70	52.72
7	49	1	180.0	77.0	23.8	1.19	171	176	47.25	45.50	43.70	44.70
8	32	1	178.0	85.0	26.8	1.16	188	175	58.00	47.50	52.60	52.50
9	33	2	165.7	58.2	21.2	1.26	187	188	47.00	41.00	40.60	43.77
10	25	1	181.5	82.7	25.1	1.21	195	190	53.00	44.50	46.00	55.93
11	47	2	169.0	56.0	19.6	1.21	173	175	43.05	32.00	31.70	32.60
12	33	1	176.0	70.9	22.9	1.2	187	183	54.00	45.00	46.00	45.41
13	24	1	188.0	91.3	25.8	1.32	196	214	49.00	42.00	37.40	39.57
14	22	1	192.0	97.3	26.4	1.22	198	192	53.00	46.00	48.50	49.61
15	45	2	160.4	63.7	24.8	1.17	171	191	44.00	32.00	26.00	35.02
16	19	1	174.0	70.9	23.4	1.22	201	193	51.00	47.00	50.40	50.37
17	26	1	190.0	92.7	25.7	1.22	194	189	66.00	52.00	53.60	55.63
18	24	2	164.0	46.0	17.1	1.21	196	190	44.00	33.00	35.50	33.60
19	59	1	182.0	86.6	26.1	1.23	160	166	45.50	31.50	29.70	30.98
20	23	1	178.0	76.3	24.1	1.25	197	192	52.00	44.00	38.10	42.04
21	25	1	184.0	87.7	25.9	1.19	196	184	59.00	52.50	56.90	60.31
22	30	1	178.0	84.0	26.5	1.42	190	189	47.25	41.00	40.60	42.99
23	29	2	164.0	65.5	24.3	1.14	191	181	58.00	42.00	44.90	54.12
24	43	1	179.0	72.2	22.5	1.15	177	172	78.40	57.00	57.30	55.60
25	21	2	164.0	54.0	20.1	1.31	199	192	45.85	42.00	44.40	43.00
26	27	2	159.0	51.0	20.2	1.34	187	193	43.00	40.00	42.70	41.38
27	27	1	174.0	82.0	27.1	1.33	193	193	52.00	44.00	44.60	42.24
28	31	2	168.0	54.5	19.3	1.22	189	184	33.00	30.00	30.70	33.55
29	20	1	176.0	74.5	24.1	1.16	200	192	56.00	46.50	49.10	46.85
30	45	2	174.0	61.0	20.1	1.28	175	186	48.00	40.00	37.30	34.70
31	31	1	180.0	70.0	21.6	1.35	189	183	52.00	44.00	45.70	46.20
32	31	2	173.0	65.0	21.7	1.16	189	182	47.00	38.00	40.80	51.37
33	46	2	173.3	61.0	20.3	1.23	174	193	46.00	46.00	40.30	42.70
34	22	1	176.0	74.5	24.1	1.41	198	206	50.05	52.00	48.10	52.88
35	20	1	182.0	82.7	25.0	1.2	200	192	48.00	38.00	42.20	41.64
36	23	1	179.0	72.0	22.5	1.23	191	204	59.85	65.00	60.00	66.06
37	51	2	157.9	52.7	21.1	1.15	169	171	48.00	37.00	36.50	36.95
38	26	1	176.0	75.0	24.2	1.18	194	181	50.00	47.00	51.40	50.95
39	25	2	165.5	59.3	21.7	1.2	195	178	47.50	40.00	45.00	44.80
40	19	1	174.0	103.9	34.3	1.25	201	194	47.50	43.00	45.70	42.10
41	32	1	184.0	73.4	21.7	1.28	188	184	53.55	52.00	56.60	54.96
42	28	1	178.2	71.2	22.4	1.26	192	185	43.75	40.00	44.40	42.72
43	34	1	180.0	81.6	25.2	1.18	186	181	57.00	50.00	52.10	46.52
44	26	2	161.0	60.4	23.3	1.16	194	188	48.00	38.00	39.10	41.40
45	45	1	184.0	106.8	31.5	1.15	175	181	43.00	45.00	42.70	41.00
46	20	2	159.0	53.6	21.2	1.47	200	191	48.00	35.00	38.20	39.70
47	27	2	170.3	59.3	20.5	1.28	193	198	44.00	45.00	44.10	41.55
48	30	1	168.5	84.7	29.8	1.17	190	180	56.00	46.00	61.50	48.61

Appendix D
(Flyer)

RUNNING PERFORMANCE TEST STUDY

If you're 30-59 years old, this is your chance!

A maximal oxygen consumption test is being conducted through
The Department of Exercise, Sport & Leisure Studies at the University of Tennessee

Walk away with the information you need for more efficient training

- VO_{2max} (maximal oxygen consumption)
- Heart rate Responses
- Optimal Training Zone

REFINE YOUR TRAINING PLAN FOR MORE EFFICIENCY

SHARE THE INFORMATION WITH YOUR PERSONAL TRAINER TO DEVELOP MORE EFFECTIVE TRAINING ZONE

Need to have two separate days

Submaximal treadmill test on the first day (take 30min)
Maximal treadmill test on the second day (take 30min)

Work out a time and a date that fits into your Schedule
Weekends or After Work
Testing Starts March 27th and Runs to April 11th

Contract Jungmin Lee for more information or to set up your testing days at:
Email address: jlee55@utk.edu

VITA

Jung Min Lee was born in Seoul, South Korea on November 23, 1976. He lived in the city of Seoul until he graduated from KangMoon High School in 1994. After high school he attended Korea University where he received his Bachelor of Science in 2003.

From 1995 to 1998, he served for the Seoul Metropolitan Police Agency as a traffic police officer. Then he decided to pursue a Master of Science in Exercise Physiology at the University of Tennessee. His future plan is to pursue doctoral studies in exercise physiology at Iowa State University (Ames, Iowa) under Dr. Gregory Welk.